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The conservation of energy

The theory of the Conservation of Energy was the greatest physical generalization of the nineteenth century, and played in the field of physics a part comparable with that of the principle of the Conservation of Matter in the field of chemistry. These two principles, which the study of atomic phenomena has shown to be interdependent, are today of such fundamental importance that it is sometimes difficult to realize that neither is much more than a century old. The present year marks an important centenary in the history of physics, for it was in 1847 that a paper was published in *The Philosophical Magazine* in which James Prescott Joule described in detail his measurement of the mechanical equivalent of heat by the famous paddle-wheel method. This investigation not only showed the precise relationship between heat and mechanical work but pointed the way to the understanding of the quantitative relationship between all forms of energy. A page of Joule's notebook, in which he outlines this historic experiment, is reproduced in Professor H. J. Fleure's article on the Manchester Literary and Philosophical Society—of which Joule was a distinguished member—elsewhere in this issue.

As with so many great scientific discoveries, Joule's work was inspired by that of certain of his predecessors and contemporaries. It was Joule's own genius, however, which first showed conclusively that a variety of observed phenomena relating to energy could be interpreted in terms of a single principle. In some respects he was, indeed, hindered by contemporary thought, for the caloric or materialistic theory of heat, according to which heat had the properties of a fluid, was common physical currency. The dynamic theory of heat, which Joule's work so firmly established, was not generally accepted until well after the middle of the nineteenth century.

The caloric theory had long found indirect support in the phlogiston theory, for until the latter was challenged there was little inducement to question the former, which had much in common with it. Caloric, like phlogiston, was supposed to be a fluid and to possess neither weight nor substance. Originally it was assumed to be highly elastic, and its particles were believed to repel one another. In a later form of the theory, such as that expounded by Marat in 1780, it was assumed that heat particles attracted ordinary matter and that heat became distributed between different bodies in quantities proportional to their mutual attractions. Although erroneous, the caloric theory, like the phlogiston theory, had much to commend it as a valuable working hypothesis. Nicolas Carnot and Lord Kelvin, for example, though ultimately accepting the dynamic theory, laid the foundations of thermodynamics on the basis of the caloric theory.

The caloric theory was first challenged when quantitative methods began to be introduced into the study of heat, just as the phlogiston theory became suspect soon after the balance was accorded importance in chemistry. The introduction of quantitative methods was due in large measure to Joseph Black, who in the latter half of the eighteenth century formulated the concepts of specific and latent heats.

The first categorical refutation of the caloric theory was made by Benjamin Thompson, Count Rumford. Rumford's observations and measurements of the heat generated during the boring of brass cannon, made while he was Minister of War in the Bavarian service, are well known. He made use of Black's methods to show that, contrary to the prediction of the caloric theory, the specific heat of the brass turnings produced while the cannon were being bored was identical with the specific heat of the original brass. His results, summarized in his classic paper 'An Enquiry

Concerning the Source of the Heat which is Excited by Friction,' were communicated by him to the Royal Society in 1798. It was in this paper that he stated his definite opinion that heat is a form of motion. Rumford's conclusions were confirmed by Davy in 1812, on the basis of observations of the melting of ice by friction. Davy, too, asserted that heat is a form of motion and that its laws are essentially the same as the laws of motion. Five years earlier the versatile physicist and Egyptologist, Thomas Young, had also expressed serious doubt of the truth of the theory of caloric.

It is perhaps not commonly known that although Rumford himself never made a quantitative estimate of the mechanical equivalent of heat, his published results make such an estimate possible. The necessary calculation was in fact made some fifty years later by Joule, who obtained a value of the same order of magnitude as he had himself deduced from his own much more precise experiments.

A calculation of the mechanical equivalent of heat was made by Julius Mayer on the basis of the difference in the work required for the adiabatic and the isothermal compressions of a gas. Mayer published his paper, 'Remarks on the Forces of Inorganic Nature,' in *The Philosophical Magazine* in 1842. Mayer himself always insisted that he had priority over Joule in determining the mechanical equivalent of heat, but the more probable interpretation of the known facts is that they arrived at their conclusions independently and at about the same time.

A clear exposition of the principle of the conservation of energy was published also in 1843 by the Danish philosopher Colding. He observed that when a loaded sledge was drawn along rails made of various materials the ratio of the heat developed to the work done was approximately constant.

Joule's first experiments in this field were made in the latter half of 1840, when he published a note on the heating effect of an electric current. Subsequently he related the heating effect to the mechanical work done in turning the electrical generator, publishing his first calculation of the mechanical equivalent of heat in 1843. In 1845 he made an independent determination by measuring the heat evolved during the compression of a gas. Later in the same year he described the method, elaborated in his paper of 1847, for measuring the mechanical equivalent of heat by rotating a paddle in a vessel containing water or other liquid. His researches in this field were summarized in the celebrated memoir which he presented to the Royal Society in 1849.

In a letter to Pictet in 1804, Rumford expressed the hope that his observations on the generation of heat during the boring of cannon would give him, within his own lifetime, the satisfaction of 'seeing caloric interred with phlogiston in the same tomb.' His hope was disappointed, and it was Joule's work which was primarily responsible for bringing about this result. Even as late as 1856, however, some standard works of reference gave precedence to the caloric theory—a good illustration of the difficulty the pioneer so often meets in gaining general acceptance of new ideas, no matter how well substantiated they may be.

The determination of the mechanical equivalent of heat did far more than provide a very important physical constant. The fact that it was a constant, by whatever method determined, established the general principle of the conservation of energy, in the full enunciation of which much was owed to Helmholtz in Germany and Colding in Denmark. The progress of science does not consist merely in the unceasing collection of new facts, indispensable though this process is, but in the interpretation of these facts in terms of a relatively small number of general principles. Joule's work, inspired by the work of those who preceded him, is of particular note because it fell to him, as it does to very few, to establish one of those principles the discovery of which marks a well-defined stage in the advance of science.

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X-rays and the carbon atom

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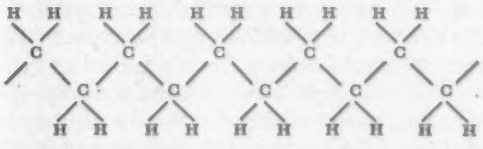
Life itself, as well as a wide range of human activities, depends upon the properties of carbon atoms, which are unique in the extent of their ability of linking together to form complicated molecules. In recent years X-rays have proved a valuable supplement to classical methods of studying the architecture of complex substances, and have provided information about the shapes of molecules and interatomic distances, especially in the case of organic compounds, which is obtainable in no other way.

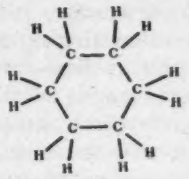
The carbon atom occupies a unique place in the periodic table of the elements. It is neither electropositive like the metals nor electronegative like the halogens, although on occasion it can behave like either. In forming compounds it prefers neither to surrender nor to accept electrons, but to share them with other atoms. It can combine with elements of widely differing properties. With other carbon atoms it can combine to an unlimited extent.

Carbon, being quadrivalent, has four outer electrons to share, and chemists have long believed that when it forms four single covalent bonds, as in methane (CH_4), its valencies are tetrahedrally directed. In carbon tetrachloride (CCl_4), carbon is combined by single covalent bonds with four chlorine atoms tetrahedrally disposed about it. In chloroform ($CHCl_3$), however, the tetrahedron is a little flattened, and the chlorine atoms are a little farther apart than in CCl_4.

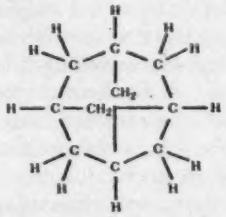
One of the carbon valencies can be used, as in ethane ($H_3C.CH_3$), to form a bond with another carbon atom. By an extension of this process carbon atoms can form long, open chains fringed by hydrogen atoms, or closed chains of various kinds. Examples of open-chain molecules are provided by the paraffins, the fatty acids, and the alcohols. Perhaps the most striking of the carbon-chain molecules is that of polythene (*below*), in which many thousands of atoms are linked together, forming a substance of unique electrical and mechanical properties.



By way of contrast with the relatively infinite molecule of polythene there are such finite, closed molecules as those of cyclohexane:



and adamantine:



In all these carbon compounds there are only single bonds between the carbon atoms.

Carbon may, however, also form double bonds, as in ethylene

or in carbon dioxide (O=C=O), the substance which contributes more than any other towards which perhaps contributes more than any other towards linking chemistry with the sciences dealing with living matter.

Carbon can form triple bonds, as in acetylene (H—C≡C—H) or hydrocyanic acid (H—C≡N), but it does not form quadruple bonds. There is no finite molecule Si≡C or C≡C. When carbon combines with carbon only, it forms infinite molecules. But it can do this in more than one way. Diamond is essentially pure carbon, and so is graphite (although both are usually somewhat impure), and yet they are very different. Pure diamond is colourless and hard, and has a very low electrical conductance and low diamagnetic susceptibility. Its density is about 3·5 gm.

per c.c. Graphite is black and soft, and has high electrical conductivity and large diamagnetic susceptibility. Its density is only 2·3 gm. per c.c. These differences can result only from the way in which the atoms are joined together, that is, from the *structure*. Both are scientifically interesting and industrially important, but both of them still present some unsolved problems.

How can we determine a structure composed of atoms which are themselves only about 0·015 millionth of a centimetre (1·5 A) apart? The answer is that we can do so only if there is some regularity in the atomic arrangement, if it repeats in space so as to form a *pattern*. All solid substances are, in fact, crystalline; that is, they are built up as a regularly repeating three-dimensional atomic pattern. The arrangement of the pattern on a wallpaper or a honeycomb can be seen directly. If the pattern we want to see is too small to be distinguished with the naked eye, we look at it with a microscope. In either case we are using light-waves. But we cannot distinguish two objects separately unless the distance between them is at least one-third of the wavelength of the light we are using, that is, at least 1,500 A, and the distance between the carbon atoms in diamond is only one-thousandth of this value. An electron microscope, used in conjunction with special techniques for the preparation of specimens, will resolve down to as little as 15 A, but this is still too gross to show us the detail of the diamond or graphite patterns. It so happens, however, that the wavelengths of X-rays are of the same order of size as the distances between the atoms, and they will also affect a photographic film in just the same way as do light-waves or electrons. We cannot use X-rays to see the atoms in the crystal directly, but the regular atomic arrangements can scatter the X-rays in such a way as to give regular diffraction patterns, which can be recorded photographically. The atoms of a liquid or a gas will also scatter X-rays, but they do not give a pattern because they are not regularly arranged. They give no more than diffuse rings from which the *average* distance apart of the atoms can be calculated. The X-ray diffraction patterns given by solids are sometimes quite beautiful, but their interest to the scientist lies in the fact that they can be used to deduce the exact arrangement of the atoms, and even to tell us the distribution of electron density in and between the atoms. This cannot be done directly. It involves a good deal of mathematical calculation, although some aspects of the atomic pattern, for instance its symmetry, can often be found by inspection. The diffraction pattern obtained depends not only on the substance examined and the kind of X-rays used, but on the particular experimental technique adopted. Some typical patterns for carbon compounds are shown in the accompanying illustrations.

Such measurements show that in diamond there is tetrahedral symmetry, each carbon atom being tetrahedrally attached to four others by single bonds, thus building up one large three-dimensional molecule, which is very hard and has a very high melting-point because of the strength of the covalent bonds between the atoms. There are no weak links in the chain. In fact, diamond never does melt: it is either converted into graphite or it sublimes. The hardness of the diamond is its most important industrial property: of all the diamonds now mined, about 80 per cent. by weight are used for industrial purposes and eventually destroyed. Owing to its structure diamond is an excellent conductor of heat but has a very small coefficient of expansion. Glass, because of its low thermal conductivity and large coefficient of expansion, cracks even when it is put into boiling water, but diamond can be brought to a bright red heat and plunged into liquid air without any harmful effects. This also is most important industrially, because diamonds used in high-speed engineering tools get very hot and must not crack or wear away too rapidly. With suitably shaped holes drilled through them, diamond dies are used for drawing the extremely fine tungsten wires needed for electric lamps and valves. A rod of tungsten 6 ft. in length and as thick as a pencil will yield a thousand miles of such superfine filament, finer even than a spider's thread. Diamonds are used in machine tools, and in drills which can penetrate the earth's surface to depths of over 10,000 ft. The famous Simplon tunnel, opened in 1906, was the first major engineering project in which the diamond drill was employed, and it has since been used in many mining and engineering enterprises. The high refraction and dispersion of light-waves, which give diamonds of gem quality their sparkle and fire, are also due to the structure of the crystal.

The structure of graphite is quite different. The carbon atoms no longer have tetrahedral symmetry, and the bonds between them are not single bonds; nor, however, can they be double bonds, for each atom is linked up with *three* others to form a plane hexagonal network. Since the four carbon valencies are shared between three bonds, the order of each bond must be 4/3. Graphite

consists of such hexagonal sheets of atoms piled together to form a layer structure, with very weak forces between the layers. It is this layer structure, with very strong forces between the carbon atoms in the planes and very weak forces between the planes, that gives graphite its peculiar properties. Since the layers slip easily on one another, graphite is an excellent lubricant. Graphite layers are put on to the paper when we write with a 'lead' pencil, or on to the stove when we polish it with 'black lead.' The same process occurs when we use carbon paper, and Indian ink is finely ground graphite baked up with a glutinous base. Since the graphite layers are so loosely held together it is possible to push many different kinds of atoms between them. This explains the fact that the rather impure forms of carbon obtained when carbonaceous matter is burnt have the power of absorbing gases and of removing colouring matter from solution. They are used, for instance, to make sugar white for table use.

X-ray photographs can give not only the structure of a crystalline substance but a measure of the size of the little crystallites of which it may be composed. Such photographs of various carbons show that they are really just graphite, but in a very finely divided state. It is, in fact, the smallness of the crystallite size that makes them absorb gases so easily. There is more surface for a given volume, and therefore more easy entrance for the gas atoms. X-rays, however, give one more piece of information besides structure and size of crystallites. They tell us how the atoms are vibrating; for the atoms in a solid are not stationary, they are constantly moving to and fro about their mean positions, and in structures such as graphite X-rays show that they move more easily perpendicular to the layers than within them. This fact explains why the absorption of gases by charcoal is so greatly increased at very low temperatures. The atomic vibration, which is of thermal origin, is much less at liquid air temperatures, and the gas atoms can penetrate the layers more easily when the carbon atoms are relatively still. The use of charcoal to absorb the last trace of gas allows double-walled metal containers to be used for the storage of liquid oxygen, hydrogen, and helium. Graphite also has most useful electrical properties. The excess of valency electrons in the layers tends to make graphite behave like a metal; it has quite a high electrical conductance in the layers, although perpendicular to them it is an insulator. In the form of gas carbon, etc., the graphite layers are orientated in all directions and the substance as a whole conducts, although pressure, by altering the orientation, will alter the resistance. The rods of arc lamps are made of fairly pure carbon, and so are dynamo brushes. Carbon is used in telephone transmitters because of the variation of its resistance with pressure, and carbon was also used in the earlier filament lamps, some of which were most ingenious. It is interesting to recall that in designing them Edison experimented with over six thousand sorts of vegetable fibres collected from all over the world.

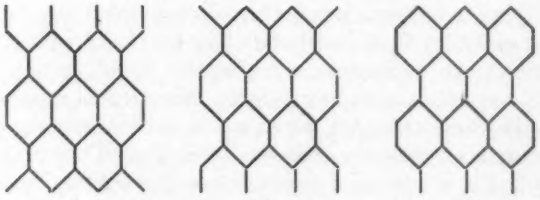
Even yet, however, we have much to learn about the structure of diamond and of graphite. X-rays can give a very accurate measurement of the distance between the carbon atoms in diamond. The distance varies from 1·54465 A to 1·54443 A in different diamonds so far investigated. This does not seem a very large variation, but it is a real one; the possible error in any one measurement is only $\pm$ 0·00002 A. These differences are doubtless due to the presence of impurity. Spectroscopic examination has shown that traces of aluminium, silicon, calcium, and magnesium are present in all diamonds examined, and other, heavy, elements are present in some, but the method used could not have detected the presence of hydrogen, boron, nitrogen, oxygen, or other light elements, some of which are quite probable impurities. We do not know, however, how the impurity enters into the diamond lattice in such a way as to expand or contract it as a whole, which is what the X-ray results indicate. Then again, there are some effects on X-ray photographs which have not been explained at all. We do not know what causes the little triangles of spots seen near the centre of figure 1, though we do know that one triangle is given by Cu$K\alpha$ and the other by Cu$K\beta$ radiation (the two main wavelengths found in the X-rays from a copper target). Not all diamonds give these triangles, although most do; in some diamonds they are completely missing. They are what is known as a structure-sensitive effect, but they are not temperature-sensitive to any noticeable extent. The two kinds of diamond—those that give this X-ray effect and those that do not—differ also in other ways, although they apparently have the same structure. Their absorption of infra-red and ultra-violet radiation differs. Whereas diamonds of the type that do not give the triangle effect give an excellent divergent beam X-ray photograph of the kind shown in figure 7, those that give the effect most strongly give no divergent beam pattern at all. Sir C. V. Raman has suggested

that there are really four kinds of diamond, varying in the orientation of the tetrahedral carbon atoms.

One most intriguing fact about diamond is that although Nature has made so many, man does not yet know how to make diamonds in the laboratory. Graphite is the more stable form of carbon, and diamond can be converted to graphite, but we have not yet learned to reverse this process. It is true that some small specimens in the Natural History Museum at South Kensington, labelled as having been made by J. B. Hannay and presented to the Museum in 1880, have been proved by X-ray analysis to be real diamonds. It may be that Hannay did in fact make them; there is no valid reason for believing that he did not except that no one has yet succeeded in repeating the experiment. Hannay himself claimed only some 6 per cent. of successes in his numerous attempts.

Graphite also presents its problems. The distance between the carbon atoms in the layers, which are more strongly bound together than those in diamond, is only 1·4210 ± 0·0001 A. The layers themselves are 3·3541 A apart at 15° C. As the temperature rises, the distance between the layers increases, the average value of the coefficient of expansion over the temperature range 14·6–800° C being $28{\cdot}3 \times 10^{-6}$. The carbon-to-carbon distance in the layers, however, actually contracts at first and only begins to expand above 400° C. The average coefficient of expansion from 0 to 150° C is $-1{\cdot}5 \times 10^{-6}$, and from 600 to 800° C it is $+0{\cdot}9 \times 10^{-6}$.

Consecutive layers of atoms in graphite do not lie vertically over one another. Most graphite



I II III

consists of alternate layers such as I, II; I, II; . . ., but some graphite takes the form I, II, III; I, II, III; . . ., and a small percentage consists of layers randomly arranged. The curious thing is that natural graphites from different parts of the world, and even artificial graphites, seem to have a fairly uniform 80 per cent. of the I, II; I, II structure and 14 per cent. of the I, II, III; I, II, III structure. Faint lines on the graphite powder photographs, as yet unexplained, indicate the presence of further structures. Graphite can also form addition compounds with atoms such as potassium or radicals such as SO_4, which fit between the layers in a regular way; here again a wide variety of arrangement of the graphite layers seems to be possible.

When carbon is mixed or combined with other elements it yields products of great industrial importance. Tungsten carbide is comparable in hardness with diamond, and we are very familiar indeed with the effects of adding small quantities of carbon to iron. Cast iron, which contains upwards of 1·5 per cent. of carbon in graphite form, is very brittle, but it is cheap, readily melted and cast into any desired shape, and is strong in compression. It is used for purposes where cheapness is important and high resistance to shear unnecessary: for lamp-posts and guttering, for example. The range of steels includes very soft steels, mild steels, and medium grades. All these contain less than 1·5 per cent. of carbon; they owe their varying characters almost entirely to the way in which, through suitable heat-treatment, the carbon atoms can be made to fit themselves into the iron framework. The effects both of heat-treatment and of mechanical treatment can be followed by means of X-ray photographs.

From the purely scientific point of view it is of great interest to know how the structures of the various carbon compounds are related to those of diamond and graphite, since these are so different from one another. Generally speaking, the carbon compounds can be divided into two broad groups. There are the aliphatic compounds, in which the carbon–carbon bonds are single; and there are the aromatic and conjugated compounds, in which, as formulated at least, there are both single and double bonds, occurring alternately. The aliphatic compounds include both open and closed chains; the closed chains may be composed entirely of carbon atoms, as in cyclohexane, or the chain may include oxygen or other atoms. In all the aliphatic compounds the carbon–carbon bonds are similar, from a structural point of view, to those in diamond. They are about 1·54 A in length, and bonds from the same carbon atom are tetrahedrally disposed. But there is one significant difference. In diamond the whole crystal is one big molecule and all the bonds are equally strong. In the aliphatic compounds the molecules are of finite size (even in polythene they are 'infinite' in one direction only) and the forces

FIGURE 1 – *Laue photograph of stationary single crystal of diamond, using the X-rays from a copper target, recorded on a plane film. Note the two little triangles of spots on each side of the central Laue reflection. The origin of these is not understood.*

FIGURE 2 – *Rotation photograph of diphenyl butadiene* ($C_6H_5.(CH)_4.C_6H_5$). *CuK radiation; plane film.*

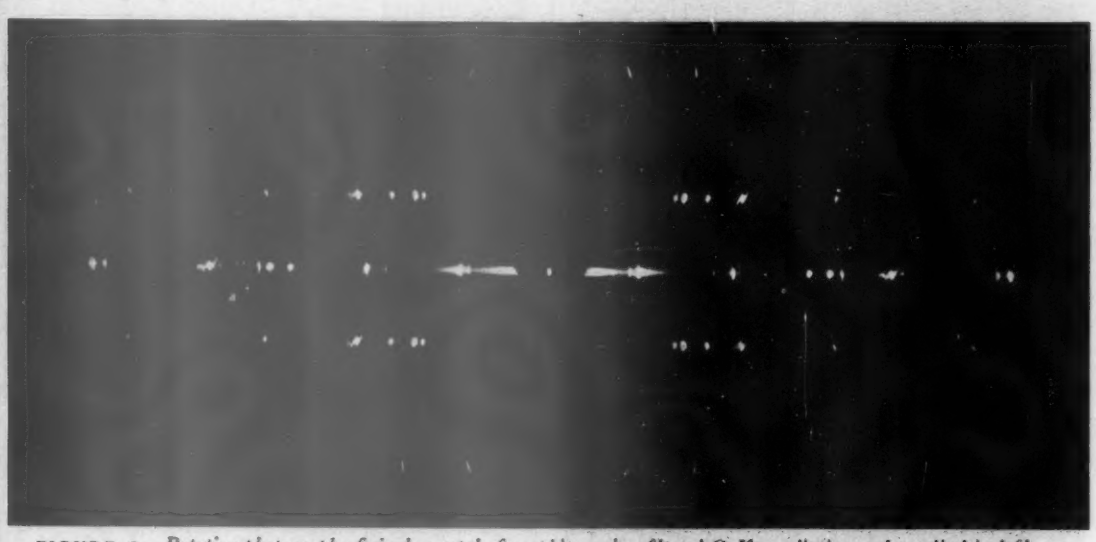


FIGURE 3 – *Rotation photograph of single crystal of graphite, using filtered CuK*α *radiation and a cylindrical film.*

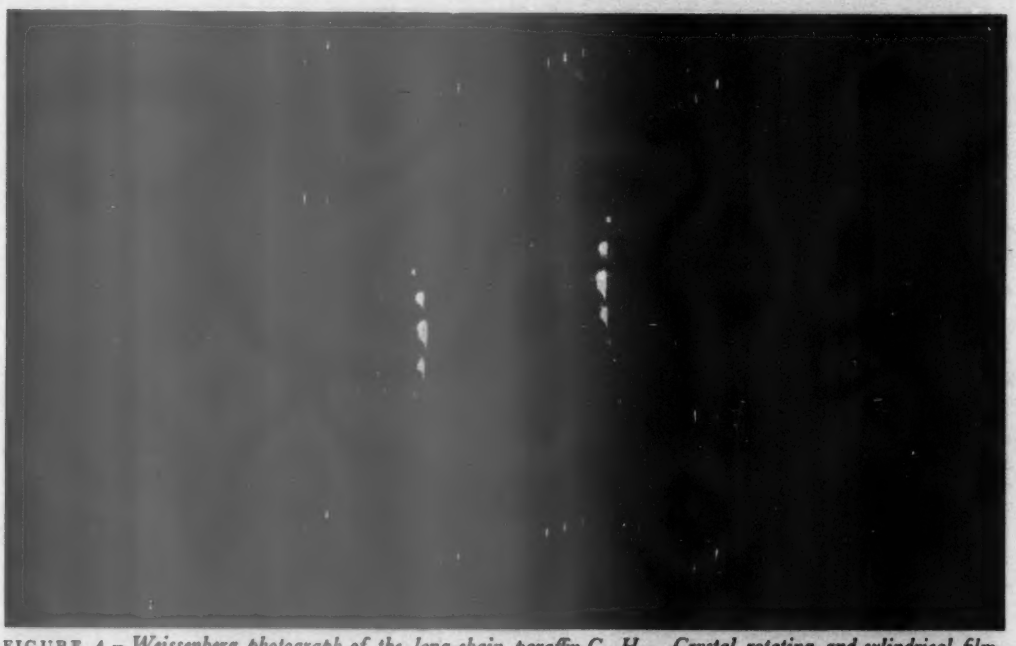


FIGURE 4 – *Weissenberg photograph of the long-chain paraffin* $C_{18}H_{38}$. *Crystal rotating and cylindrical film moving synchronously to and fro.*

FIGURE 5 – *Powder photograph of cyclohexane at liquid air temperatures. (At ordinary temperatures cyclohexane is a liquid, without a regular arrangement of molecules.)*

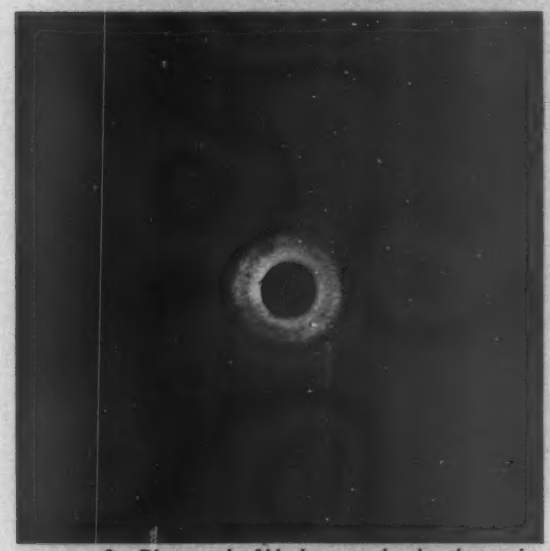


FIGURE 6 – *Photograph of black paper, showing the powder rings of cellulose.*

FIGURE 7 – *Divergent beam photograph of a single crystal of diamond. Such photographs, if taken at long distances, can be used to give very accurate measurements of the carbon–carbon distance in individual diamonds.*

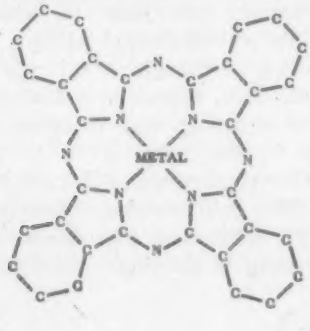
between the molecules are weak; in pure hydrocarbons they are as weak as those between the layers in graphite. The distances between the molecules are also of the same order as in graphite, about 3·5 A. If the molecules contain oxygen or nitrogen, the linkages between molecules may be formed by hydrogen atoms. The length of a hydrogen or a hydroxyl bond is 2·5–2·9 A, much longer than the single carbon–carbon bond but not so long as the 3·5 A of the so-called 'van der Waals' bond in graphite. The only carbon compound which is similar in structure to diamond is carborundum (SiC), although even carborundum differs from diamond in also having several alternative structures, in all of which the crystal is one giant molecule. Carborundum, though not so hard as diamond, is nevertheless very hard indeed and is used as an abrasive. Aliphatic compounds, on the other hand, are soft and have low melting-points, because it is so easy to break the bonds between the molecules.

It is a curious fact that even very long aliphatic chains tend to lie parallel to one another, like matches in a box. This is the reason for the formation of soap-bubbles, which are composed of chains of carbon atoms, fringed by hydrogen atoms, standing side by side perpendicular to the bubble surface. The fatty acids, such as stearic, palmitic, and oleic, are essential constituents of oils, fats, waxes, and soaps. These long-chain compounds have a very active group, such as —COONa in the case of soaps, at one end of the chain. When a layer of oil spreads over the surface of water, the active groups fasten themselves tightly to the water surface, while the carbon chains to which they are attached stand up like the pile of of a carpet, holding tightly to each other side by side. The long chains of polythene do not form parallel bundles over the whole of their length, but one molecule will form part of several crystallites, the regions between crystallites being disordered and the crystallites themselves radiating from centres; it is possible, however, to cold-draw polythene so that the crystallites become aligned.

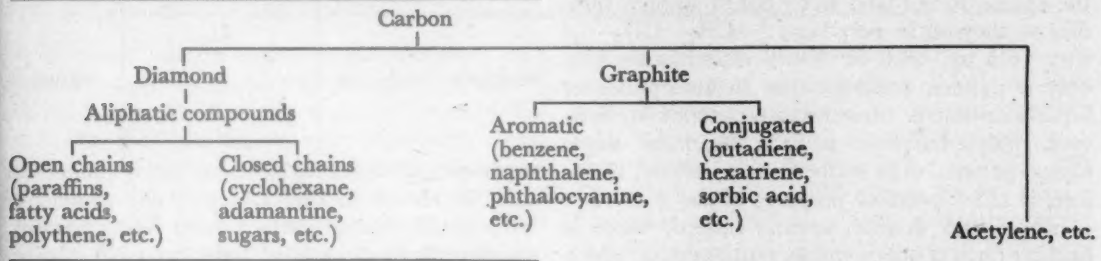
Owing to the tetrahedral arrangement of the single carbon bonds, the carbon rings in cyclohexane and in the sugars are of a zigzag formation, but the rings in aromatic compounds such as

benzene, naphthalene, anthracene, toluene, and so on are quite plane, and the carbon–carbon distance is only about 1·39 A. In these compounds the carbon–carbon bond is intermediate between a single and a double bond, as it is in graphite, and in many respects the condensed benzene derivatives resemble graphite quite closely. If placed in a magnetic field and free to move, they will turn sharply, as graphite does, so that the lines of force lie as nearly as possible parallel to the planes of the molecules. The distance between neighbouring molecules is again about 3·5 A, except where the connection is made by means of hydrogen or hydroxyl bonds. The very large closed ring of carbon and nitrogen atoms which, with its four attached benzene rings, forms the phthalocyanine nucleus, is also aromatic in nature, and electron density determinations by means of X-ray analysis show that the whole molecule is quite flat. In fact, it is so determined to be flat that metals placed in the centre of the nucleus are obliged to form plane bonds to fit on to it, even when they are elements, such as beryllium, which would usually be tetrahedrally co-ordinated. Copper phthalocyanine is the dye known commercially as 'Monastral Blue,' a dye which is normally quite unchanged by light, heat, or chemical action.

In conjugated compounds, such as butadiene ($H_2C{=}CH{-}CH{=}CH_2$) or sorbic acid ($H_3C{-}CH{=}CH{-}CH{=}CH{-}COOH$), where there is an open-chain formation of double and single bonds, X-ray measurements show that there is a tendency for the bonds to equalize. The 'double' bond is definitely longer than a real double bond should be, and again the molecule tries to be flat. In fact, it is flat unless prevented from being so by large substituent groups which get in each other's way. Again, the crystal will try to turn in a magnetic field so that the molecular planes are parallel to the field. This behaviour in a magnetic field shows that there are some electrons (those same electrons which give graphite its semi-metallic properties) which can wander over, or are shared by, all the carbon atoms in the molecule.



The relationships between the structures of the simple carbon compounds can be shown diagrammatically as follows:



There is one group of substances, however, which it is difficult to allocate to any of these divisions: this is the rubbers. Rubber is essentially a high polymer of isoprene $\left(\begin{matrix}H_2C{=}C{-}CH{=}CH_2\\ \quad\quad\quad|\\ \quad\quad\quad CH_3\end{matrix}\right)$. The tendency of the double and single bonds to equalize means that each partakes to a certain extent of the nature of the other, and it is not difficult for the bonds to swing over so that polymerization follows. $\left(\begin{matrix}H_2C{=}C{-}CH{=}CH_2\\ \quad\quad\quad|\\ \quad\quad\quad CH_3\end{matrix}\right)$ becomes $\left(\begin{matrix}-CH_2{-}C{=}CH{-}CH_2-\\ \quad\quad\quad|\\ \quad\quad\quad CH_3\end{matrix}\right)_n$ and in the polymer there is then a 3 : 1 sequence of single and double bonds.

Rubbery chains, of which this is one, tend not to align themselves side by side as the long-chain paraffins do, but rather to curl up, forming a structure which has no definite pattern in space and which gives X-ray photographs similar to those of liquids. Fully stretched, however, rubbers give X-ray photographs similar to those of single rotating crystals. The chains not only become straightened out in the stretching process, but when straight their sideways linkages show regularity over a considerable number of molecules. X-ray examination of simple carbon compounds in which there are three single bonds between two double bonds has shown a further surprising fact,

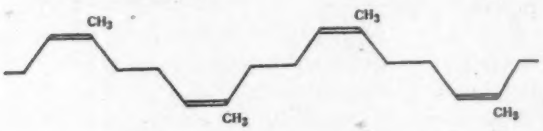
which is that the middle bond of the three is shorter than a single bond ought to be. The chain apparently tries to acquire some degree of conjugation, though why it does so we do not yet know.

Many other high polymers are similar to rubber mechanically.

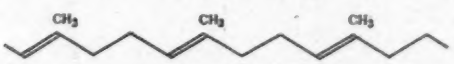
Isobutylene $\left(\begin{matrix}CH_3\\ \\ CH_3\end{matrix}\!\!>\!C=CH_2\right)$

polymerizes to polyisobutylene $\left(\begin{matrix}CH_3\\ \\ CH_3\end{matrix}\!\!>\!C-CH_2-\right)$

and although the bonds are now all single bonds the chains do not tend to lie out in straight bundles as they do in polythene $(-CH_2-CH_2-)_n$; they curl up, and on X-ray examination give only a pattern corresponding to amorphous or liquid substances. Stretched a thousandfold, however, polyisobutylene gives a beautiful single crystal pattern. The rubberiness of rubber, therefore, is not a peculiar property of the 3 : 1 ratio of single and double bonds. Indeed, there is another form of polyisoprene, gutta-percha, which is not rubbery at all, but is a horny crystalline substance. X-ray studies indicate that rubber is the so-called *cis*-form, which when stretched gives a chain of this type:



while gutta-percha is the *trans*-form, of the type:



The most important carbon compounds of all, however, are those that occur in living matter, whether of vegetable or of animal origin. In the presence of sunlight, green plants can assimilate the carbon dioxide of the atmosphere and, with water, can build up carbohydrates, which then form polysaccharide chains, of which the best known is cellulose. Vegetable fibres such as cotton and hemp, and the regenerated forms of cellulose fibres such as the artificial silk 'viscose,' give excellent X-ray pictures. These pictures show that the polysaccharide chains must be fully extended, since they give a regular pattern. There are, however, many ways of arranging the same number of carbon, hydrogen, and oxygen atoms. Cellulose is only one way; the alginic acid occurring in seaweeds is another, and this also can be used to make an artificial silk yarn. In fibres the crystallites are all arranged with their lengths parallel or nearly parallel to the fibre axis. (In the case of cotton they are spiralled about it.) In paper or Cellophane, however, they are disarranged, as the X-ray patterns clearly show; paper gives a typical 'powder' pattern (figure 6).

Animals cannot assimilate carbon dioxide, but they need carbon in order to build up proteins, which can be broken down and rebuilt as required. Protein chains are not pure carbon chains; nitrogen is an essential constituent. They are polypeptide chains, built up by the combination of amino-acid residues such as , where R represents different side-groups. Such chains can exist in almost infinite variety. The protein of natural silk, fibroin, gives a good X-ray pattern, showing the existence of fully extended chains. The patterns given by wool, horn, and hair on the one hand, and muscle on the other, are not so good; but they are curiously alike, showing that in spite of their different chemical constitutions wool and muscle must be architecturally similar. Each gives a typical pattern when unstretched and a different pattern when stretched, but in both states the two substances are structurally alike. X-rays have shown that the protein structures of birds and of reptiles are related. Synthetic fibres such as nylon also give excellent patterns.

Some of the patterns given by the globular proteins such as insulin and haemoglobin, and by the viruses, are so elaborate and so full of information that they are almost more than the present analytical technique can deal with. The recent complete analyses of cholesteryl iodide and of penicillin, however, by the X-ray method used at its highest power, encourage us to think that these other carbon compounds will also, one day, yield up the secrets of their structures.

There remains one field in which X-ray methods have proved disappointing. Many synthetic plastics, although highly polymerized carbon compounds, appear to possess little or no regularity of structure, and therefore give little information in the form of X-ray diffraction patterns. There is, however, still much to be done before we fully understand the structure of the chains, rings, webs, and frameworks of carbon atoms that occur in the simpler compounds.

The Manchester Literary and Philosophical Society

H. J. FLEURE

The great influence of science upon the development of religious beliefs has been frequently discussed, but the reverse process, the influence of religion upon the development of science, has not always received the same attention. This latter process is, however, a by no means negligible one. The formation of the Manchester Literary and Philosophical Society, one of the oldest British scientific societies, was, as the author here shows, due in some measure to the attempt made in 1662 to establish uniformity of religious belief throughout Britain.

It was especially in the seventeenth century that thinking men first realized that truth may, indeed must, be sought by observation and experiment, that even Aristotle was not a final authority. This momentous realization, in an era dominated by hardened dogma—with persecution an attendant commonplace—drew inquirers together into groups for exchange of thought and mutual encouragement. After the time of Bacon, Gilbert, and Harvey, the outstanding example in Britain is the group which in due course became the nucleus of the Royal Society. The society received its charter from King Charles II in 1662. In some other countries, academies were called into existence by the State and became in considerable measure State institutions. It is characteristic of the British tradition that this movement was, and remained, separate from the organization of the State, however much the State might at times confide various inquiries to the society. In 1662 the Act of Uniformity, which aimed at the establishment of a definite standard of belief and practice in the Episcopal Established Church, came into force. A number of clergy were in consequence ejected from their livings, a notable instance being John Chorlton of Manchester parish church (now the cathedral). He, like many another ejected minister, formed a dissenting congregation which was on the whole less liable to persecution in a place that was not a chartered borough. Birmingham and Manchester were not boroughs, and they developed strong and thoughtful dissenting groups to such an extent that at the end of the nineteenth century it was said that the greater part of the intellectual life of south Lancashire and of Birmingham was associated with Unitarianism and the Society of Friends.

The dissenting groups of the seventeenth century were deeply interested in Calvinistic theology and its philosophical background. They were thus in a sense the continuation of medieval scholasticism outside the more formally authoritarian churches. When toleration developed a little further after the revolution of 1688, John Chorlton's group built Cross Street Chapel, Manchester (1694), as a Presbyterian institution, and Chorlton had Henry Newcome as assistant pastor. As the historic universities and grammar schools were, and long remained, exclusively episcopalian, the dissenting groups were driven to think of education outside the barriers, and were thus impelled towards at least nominal freedom of conscience and, consequently, of discussion. In 1699 Chorlton and Newcome 'set up teaching university learning in a great house in Deansgate,' Manchester, with a five-year course in Arts and Theology. This was an early academy, but not the earliest, as Henry Newcome himself had been educated under Richard Frankland at Rothmell Academy.

The students of this early Manchester Academy were taught by Chorlton and Newcome and used Cheetham's library. After Chorlton's death, another dissenting minister, James Coningham, became a teacher, but with the rise of Tory policy under Queen Anne he had to face threats of prosecution for 'keeping a public academy.' He moved to London in 1712, with the result that the Manchester Academy ceased to function.

The historian of the school and academy at Carmarthen, Professor R. T. Jenkins,[1] described the special features which characterized the eighteenth-century education in the academies:

1. The great prominence given to mathematics and science.

[1] R. T. Jenkins, *History of Carmarthen*, edited by Professor Sir John Edward Lloyd, vol. ii, p. 237 (1939).

2. The inclusion in the philosophy course of systems which had not yet secured entry into Oxford, such as those of Locke and of the Scottish philosophers.
3. The requirement of a high standard of Hebrew for ministerial candidates.
4. The use of English in place of Latin as the vehicle of instruction.

A very important academy founded at Warrington in 1757 lasted until about 1783. This academy seems to have derived prestige from the fact that Joseph Priestley, who had been minister at Cross Street, Manchester, taught at Warrington (1761–7) before moving to Leeds. Among his pupils was Thomas Percival, founder of the Manchester Literary and Philosophical Society (1781) and of the second Manchester Academy (1786), which replaced the defunct Warrington institution. Percival, who was born in 1740, came of a Warrington medical family. The affluence of the family permitted his travelling on the Continent and attending universities there. His educated and attractive personality secured for him election into the Royal Society of London at the early age of 25. He seems to have been distinguished rather for his general wisdom and dignity than for any outstanding originality in investigation or any special power of exposition.

The dissenting groups and the academies in the eighteenth century were in a special sense discussion groups. Among them there appeared the usual cleavage between the more liberal and the more authoritarian type of mind. The former tended towards Unitarianism, or, as it was sometimes called, non-subscribing Presbyterianism. The authoritarians tended to react against the Unitarian doctrine, and we find Calvinistic and Arminian groups emphasizing the doctrine of the Trinity.

These trends in controversy made the academies, and other schools based on freedom of conscience, more particularly Unitarian; and Cross Street Chapel became Unitarian in fact, although it retained the Presbyterian name. Percival, as a loyal disciple of Priestley, was a leading figure in this development. After he had left Warrington, Priestley spent a year at Leeds (1767–8) and then went to Birmingham, where a 'Lunar Society' was formed, deriving its name from the fact that it met on nights of full moon. The Lunar Society was paralleled by groups in other towns such as Bristol, Dublin, Edinburgh, and Norwich, but the original society had exceptional strength, as it included Erasmus Darwin, Boulton, Watt, Priestley, and Wedgwood. It has been said that it was too strong to last, and, as these famous thinkers died or moved away, the Lunar Society disappeared. We gather that an informal group met in Manchester for some years at Percival's house in King Street, and that his friend and fellow-disciple of Priestley, Thomas Barnes, minister of Cross Street Chapel, was an active member of the group. Hints of their activities are vouchsafed through Percival's proposal for more accurate and comprehensive Bills of Mortality in Manchester (1773), and by his interest in proposals for more comprehensive and accurate parish registers. These efforts of Percival led to the formation of the Manchester Board of Health in 1796.

In 1781, the group around Percival formed themselves into the Manchester Literary and Philosophical Society, with Peter Mainwaring, M.D., and James Massey, Borough Reeve of Salford, as Joint Presidents. The earliest meetings of the society were held at the Assembly Coffee House, but, before the end of 1781, the chapel room of Cross Street was the established place of meetings. Percival, who is reputed to have been one of the first medical men to use cod-liver oil in cases of threatened tuberculosis, succeeded Mainwaring in 1782, and held the Presidency alone from 1789 until his death in 1804. That the new society was influential we gather from the fact that when, in 1786, an academy was founded or refounded in Manchester to do the work previously carried on at Warrington, it was decided that, as a mark of respect, the then officers of the society should be appointed governors.

The papers discussed at the society's meetings were very varied, but we note one by Charles White on gradations in animal forms. He noticed the evidence of such gradation, but refused to consider any idea of evolutionary development. Dr Aikin discussed 'Living in High Latitudes' and elucidated the factors of scurvy. Alexander McDougall wrote on the use of carbolic acid in the curing of wounds. When Priestley's sympathy with the French revolution led a Birmingham mob to burn his house in 1791, several members of the society wished to send him a friendly message, and Edmund Burke in Parliament denounced the sympathy of Manchester with the Jacobins. There was evidently a sharp division of opinion in the society, and some members, including the sons of Priestley and Watt, resigned.

In 1793, Manchester Academy decided to employ John Dalton as a tutor, and he joined the society in 1794. With this powerful mind to aid it

FIGURE 1 – *Cross Street Chapel Room, Manchester, in which the society's meetings were originally held.*

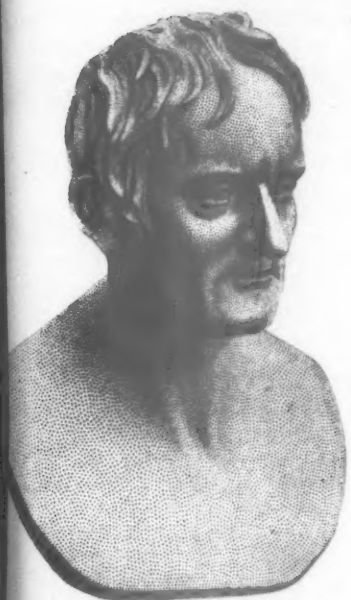
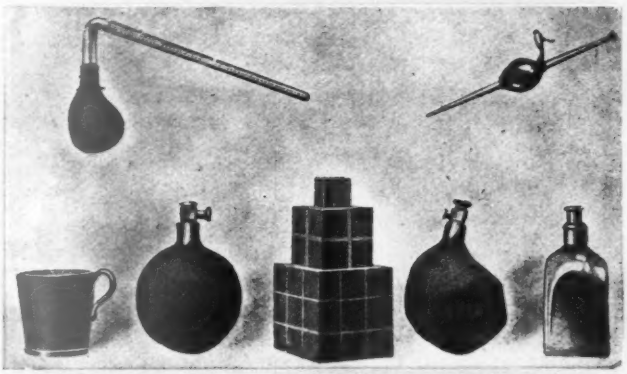


FIGURE 2 – *John Dalton.*
(From Memoirs of the Life and Scientific Researches of John Dalton, *by W. C. Henry*)



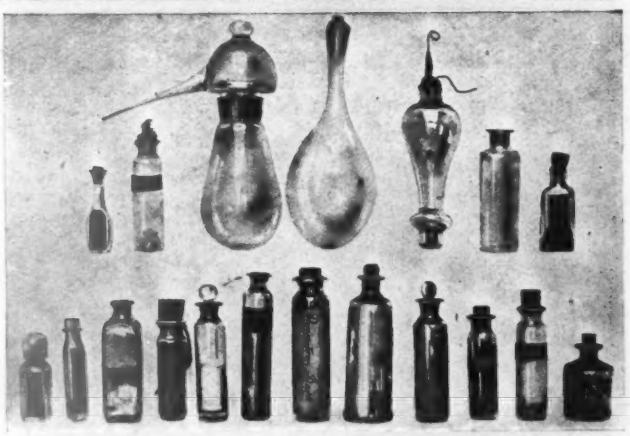


FIGURE 3 – *Some of Dalton's apparatus, destroyed in an air attack on 23rd December,* 1940. (*From* Makers of Chemistry, *by E. J. Holmyard*)

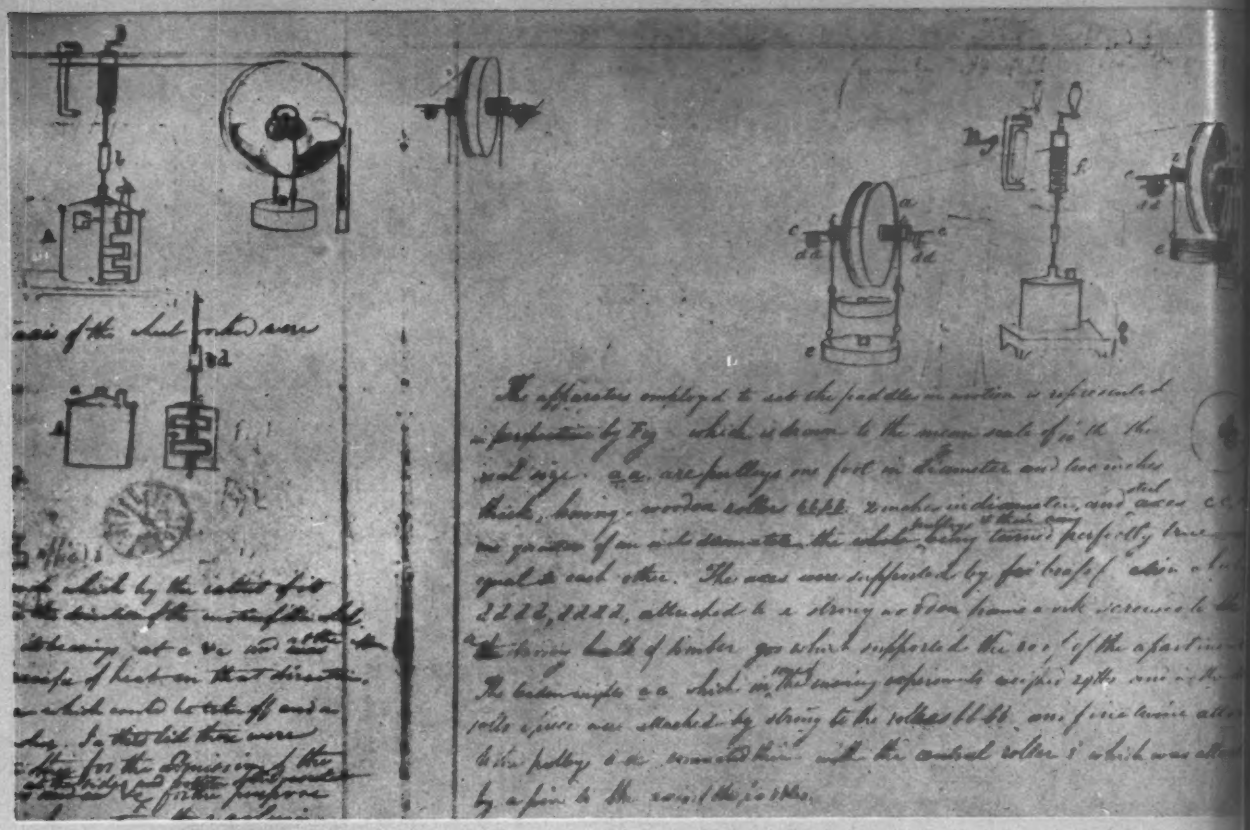


FIGURE 4 – *A copy of a page from Joule's notebook in which he sketched and described his plans for the final determination of the mechanical equivalent of heat.*

the society developed remarkably, and it has been calculated that during Dalton's fifty years of membership he read to it 116 papers, of which twenty-six are published. He became Secretary in 1800, Vice-President in 1808, and President from 1819 until his death in 1844.

Soon after joining, he read his first paper, which was the historic one on grades in colour-blindness, a paper that was based on his own defect of vision. Dalton's treatise on meteorology was another pioneer effort of his early days, and he continued to work at the subject until the end, his last paper being on the climate of Manchester. His most important work was the enunciation of the atomic theory, and a study of Dalton's efforts in this matter was published by Dr Andrew Meldrum in the society's Memoirs for 1910–11 (vols. liv and lv, New Series).

In 1799 a house at 36 George Street was bought for £600 by the society. Dalton was given a room in which to work and teach, and he lived for many years with the Rev. W. Johns in Faulkner Street not far away. As Manchester Academy was moved to York in 1803 and did not return to Manchester until 1840 (to move again in 1853, first to London, and then to settle at Manchester College, Oxford), the society's help to Dalton was no doubt very practical; it was certainly peculiarly appropriate, as the society owed its prestige almost entirely to his work.

Going back to the early days of the society, we find another name that was to become celebrated. The young Robert Owen attended for the first time in 1793, when Dr Guthrie read a paper on the nature and cultivation of Persian cotton. Owen was invited to join in the discussion, a sign that his work in connection with the improvement of fine cotton-spinning was already becoming known. During his residence in Manchester he read papers to the society on the improvement of the cotton trade (1793), the utility of learning (1793), the connection between universal happiness and practical mechanics (1795), and the origin of opinions with a view to

the improvement of social virtues (1796). They at any rate show the trend of thought which was later to produce such interesting practical results.

The Rev. Thomas Barnes, the first secretary and minister of Cross Street Chapel, was evidently a man with a social conscience ahead of his time. To a paper read by him before the society is ascribed the idea of the 'Mechanics' Institute.' The Mechanics' Institute of Manchester was founded in 1824, and was the germ of what has now become the College of Technology.

Until the forties of the nineteenth century, topics discussed by the society ranged widely, though it seems that Dalton was little inclined to vague literary discourses. H. H. Watson worked on the efflorescing properties of salts of sodium; W. Fairbairn (later Sir William) published elaborate figures concerning the strength of cast iron; and other papers dealt with the Rohan potato, the jargonelle pear, the coal of south Lancashire, the Babylonian or arrow-headed characters, and so on.

In 1842, J. P. Joule joined the society; he became its honorary secretary four years later. Times were changing rapidly in science. Specialization was developing quickly, and the Royal Society of London was becoming metamorphosed into the form it has now kept for nearly a hundred years, with election to its fellowship managed through specialist committees and very restricted as to numbers. Henceforth papers on literary and artistic topics became rare in the meetings of the society, and remained rare until an effort was begun by W. B. Wright, Honorary Secretary in the nineteen-thirties, to reintroduce these subjects.

The society soon began to suffer from the fact that papers which in earlier times might have been given to it were more and more sent to specialist societies of national status or to the Royal Society. Owens College, handsomely endowed by John Owens, was founded in 1851, and from the first some of its professors, notably W. C. Williamson, took an active interest in the society, but the institution had still to gather strength and prestige. It was increasingly felt that specialist memoirs were liable to be overlooked if they appeared in the memoirs and proceedings of such a general society as the 'Lit. and Phil.' The centenary volume of the Memoirs and Proceedings is, in places, almost querulous over this matter. It would seem that the officers and readers of papers had little realization of the field of work that Robert Owen, in his studies for social welfare, Thomas Barnes, with his educational projects, and Thomas Percival, with his concern about coal smoke, had opened up. The new prestige of the Royal Society of London was another overwhelming influence.

Henry Wilde, inventor of an improved dynamo and of better searchlights and other electrical equipment, enlarged the George Street House and gave the society about £10,000, from the interest on which a secretary's salary was paid and part of the cost of the memoirs was met. The house had by this time become one of Manchester's historic monuments, with a fine common-room containing furniture ascribed to Sheraton, portraits in oils of Newton, Davy, Dalton, Joule, Percival, and others, and a collection of Dalton's diagrams relating to the atomic theory, as well as a large collection of portraits of scientific men presented by Dr Francis Jones in memory of his father, who was Honorary Secretary 1896–1906 and President 1910–11. There were many pieces of Dalton's apparatus, his medals (including the Copley Medal of the Royal Society), and some thermometers and other objects used by Joule. But the greatest treasure of the society was its library of long runs of scientific periodicals and publications such as the Challenger Reports, the Palaeontographical Society's series, *Palaeontologia Indica*, and many more. Dalton's *Elements of English Grammar*, published by him in 1801, was among the society's intimate possessions, and it had many rare old works. In the period after the war of 1914–18 Mr R. H. Clayton, as Treasurer and President, gave much time and liberal gifts for the improvement of the house, and the Carnegie United Kingdom Trust made a considerable grant towards the binding of journals in the society's library.

The difficulty of the society was that it was living on its past, and its function was too largely that of custodian of what had become a historic house. In 1940 advice was given to the society, and unfortunately accepted, that it could keep its treasures in safe custody in its cellars. The air attack on Manchester on 23rd December, 1940, started a huge fire which spread from Piccadilly and destroyed 36 George Street so completely that only a few damaged items were ever recovered from the cellars. The society was kept alive throughout the war years 1939–45, and now appears to be entering upon a new phase of life, in which the University of Manchester, the citizens who are concerned for social betterment, and the great industries which increasingly need scientific contacts for their staffs, are playing a part.

The colours of marine animals

T. A. STEPHENSON

The functional nature of biological coloration has been studied for many years, but the greater part of the observation and experiment has been done in connection with land animals. Professor Stephenson here suggests that new fields of inquiry might be opened by consideration of the coloration of marine animals and outlines our present knowledge, with particular reference to sea-anemones. He discusses also the possibility, not always recognized, of colour schemes which are not related to physiological or ecological functions.

For many years authors have been writing about the functions of colour and pattern in plants and animals; yet, considerable as the resulting literature is, it pales beside that of some other branches of biology. Thus, while the bibliography of H. B. Cott's recent book (1940), *Adaptive Coloration in Animals*, includes 685 references, that of J. Needham's *Chemical Embryology* (1931) includes about ten times that number. For the animal kingdom, this literature has culminated in the masterly book by Cott just mentioned. This enables us to see quite clearly what has already been achieved, and shows that the knowledge we so far possess is in some ways more solid than it had seemed to be. It may be accepted that schemes of colour and pattern which conceal, advertise, or disguise their possessors are of fundamental importance in the lives of animals. Cott's conclusion that 'adaptive coloration is one of the chief attributes of the higher animals, and has been, indeed, one of the main achievements of organic evolution' is probably by no means an exaggeration. It is therefore possible to regard Cott's book as a landmark, the end of an epoch. Without implying that there is not still plenty of scope for further development in the same direction, we may consider whether there are other directions in which a new start might now be made.

It is possible that new light might be gained by a closer study of the colours and patterns of water animals as distinct from land animals, because they offer a rather different field and one less fully known. That they have received less than their share of attention is evident from Cott's book, which reflects the literature and which, although it takes marine animals (especially fishes) into account where anything is known about them, is predominantly a book about land animals. This is well brought out, for instance, by the references to coelenterates, which contribute little to the conclusions of the book, whereas these animals actually provide one of the richest fields for colour studies in the animal kingdom. This is not a criticism of the book, but a comment on the state of our knowledge.

Various interesting questions arise in connection with water animals. Why are marine animals so often brilliantly coloured and fresh-water animals so often dull? Do all the principles which have been shown to affect the coloration of land animals really apply in the sea? Do they explain what we observe in the sea wholly or only partly? Are there further principles which apply in the sea and not on land? Many such questions may be asked.

A line of study which might prove very profitable is the inquiry as to how far colour and pattern are ever *irrelevant* to the life of an animal. This would lead on to a consideration of the real meaning of non-functional colour schemes. Here again it is possible that the sea may provide better examples than the land. Although authors have long recognized that there exist types of coloration to which no functional meaning can be assigned in the present state of knowledge, attention has hitherto been focused far more upon the types with which it has been possible to link some function.

Marine animals present both explicable, or partly explicable, types of coloration and types for which no explanation is yet possible. The illustrations to this article give examples of both. The sea-urchins in plate II and the dog-whelks in plate III show examples of coloration connected with sea temperature in the one case and food supply in the other; though in the first case we do not know how the temperature affects the colour, and in the second there is probably more variation than can be explained entirely in terms of food. The sea-urchins shown develop their bright colours throughout the southern

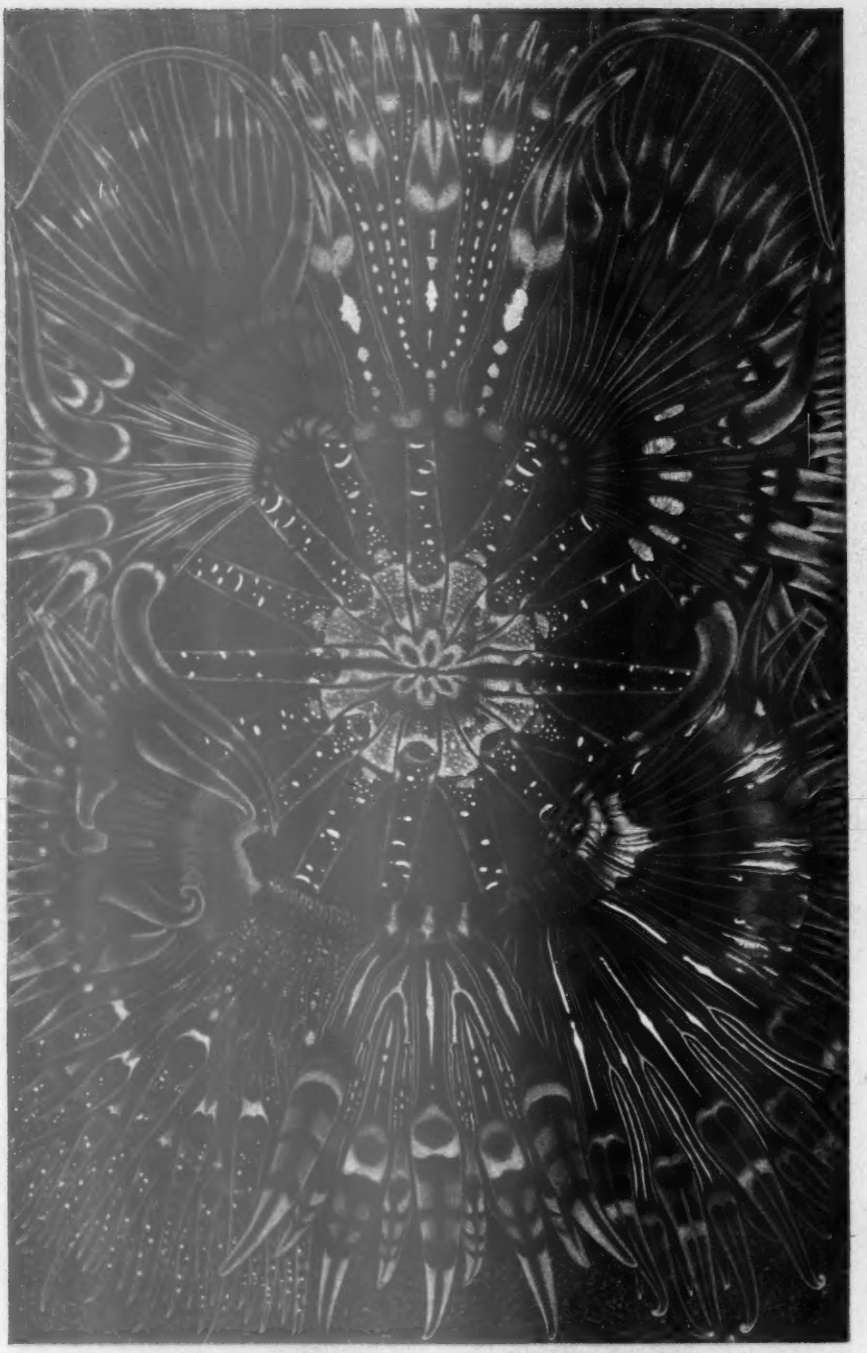


PLATE I – *The structure of the patterns developed on the disc and tentacles of eleven species of sea-anemones, represented on an enlarged scale. Except for the central figure, which illustrates the whole disc and the basal parts of the tentacles of a species of* Edwardsia *(with a dark line marking the directive axis), each figure represents a sector of the disc only, extending from the anemone's mouth outwards, with the tentacles belonging to it. The various sectors are arranged so as to facilitate comparison of the patterns with one another.*

(Reproduced from The British Sea Anemones, *by T. A. Stephenson, by kind permission of the Ray Society)*

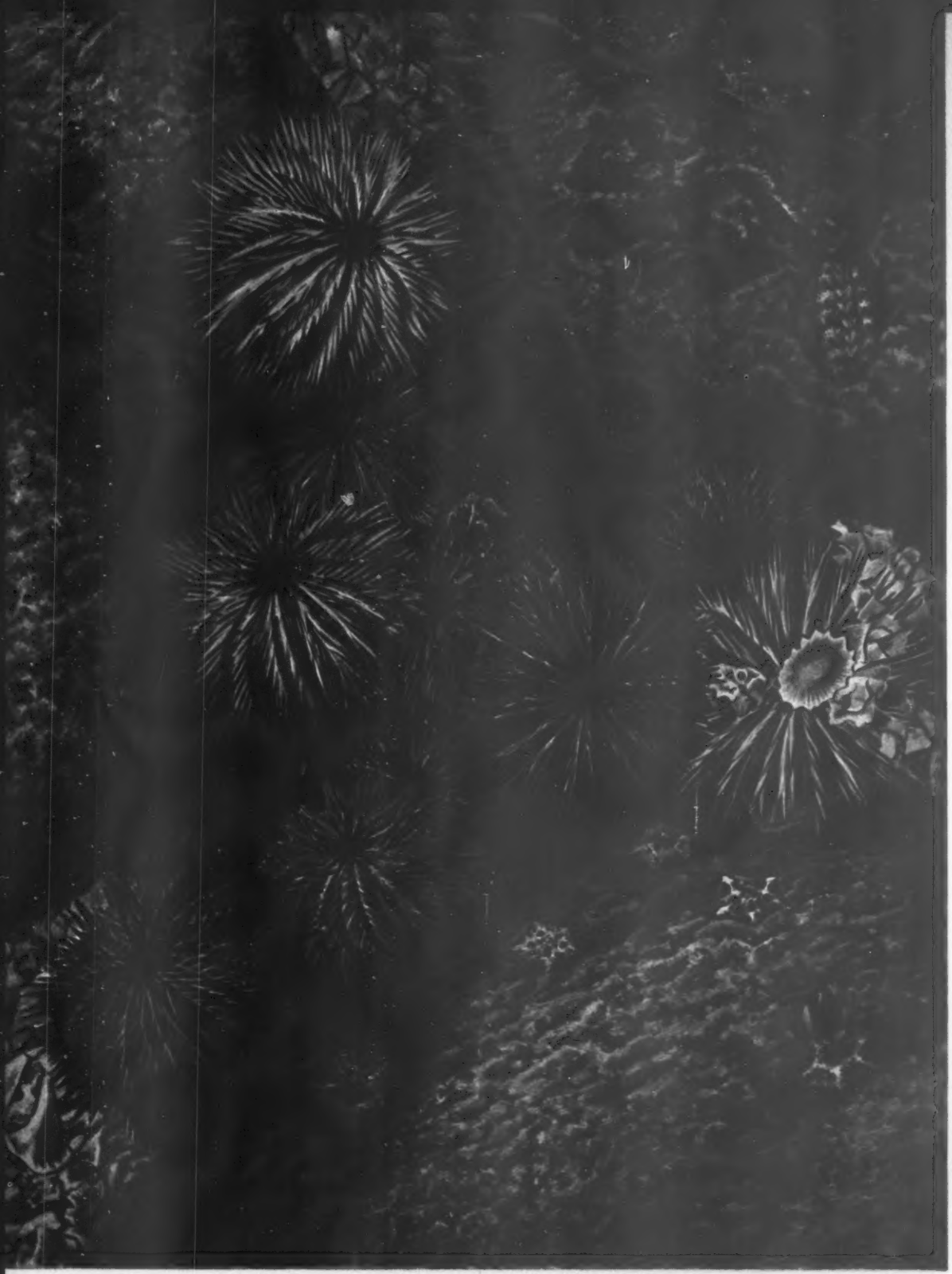


PLATE II – *A group of sea-urchins* (Parechinus angulosus) *in a rock pool in False Bay, South Africa. The purplish colour of the rock is due to an incrustation of calcareous algae. The small pentagonal objects in the lower part of the picture are specimens of a starfish* (Asterina exigua) *which also shows changes of colour, connected with water temperature, on different parts of the coast.* (*See page* 152.)

PLATE III – *A series of shells of the British dog-whelk* **Nucella (Purpura) lapillus,** *showing some of the variations in colour which occur in this species.* (*See pages* 153 *and* 158.)

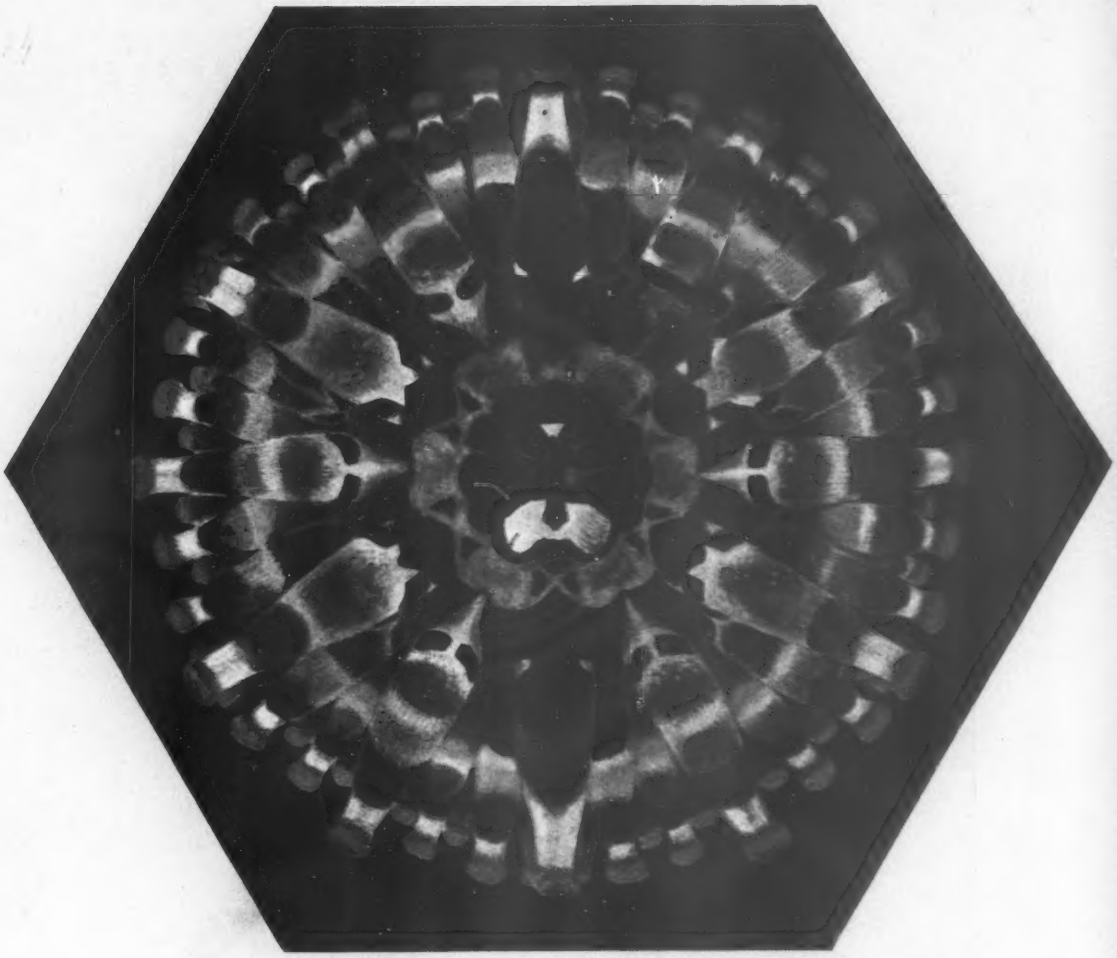


PLATE IV – *The disc and tentacles of a sea-anemone found in the interstices of branching coral on the Great Barrier Reef, Australia (about twice natural size). Some of the features of the pattern developed by this specimen are further illustrated in figure 2. The pattern is related with mathematical precision to the structural axes of the animal, and the coloration along the directive axis (vertical in the figure, and explained in the text) differs from that of the other radii in that there are opaque white marks at the opposite ends of the mouth, and much more dark colour on the two primary tentacles which lie along this axis than on the others. This change of pattern along one axis, taken together with an imperfection in the pattern in one sector (to the right of the upper directive tentacle, at* H *in figure* 2*), has a 'disruptive' effect on the general appearance of the animal as seen during life, distracting the eye to a certain extent from the very regular appearance presented by the rest of the pattern.*

SONY

XC

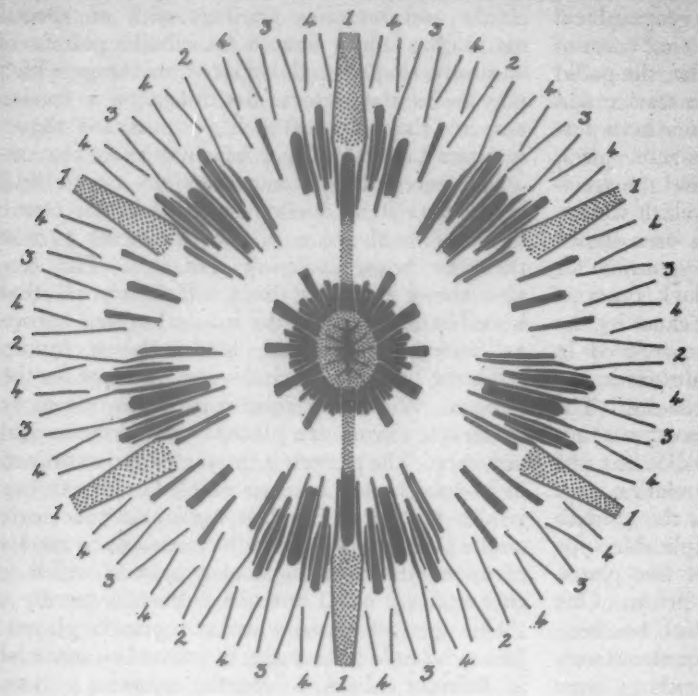
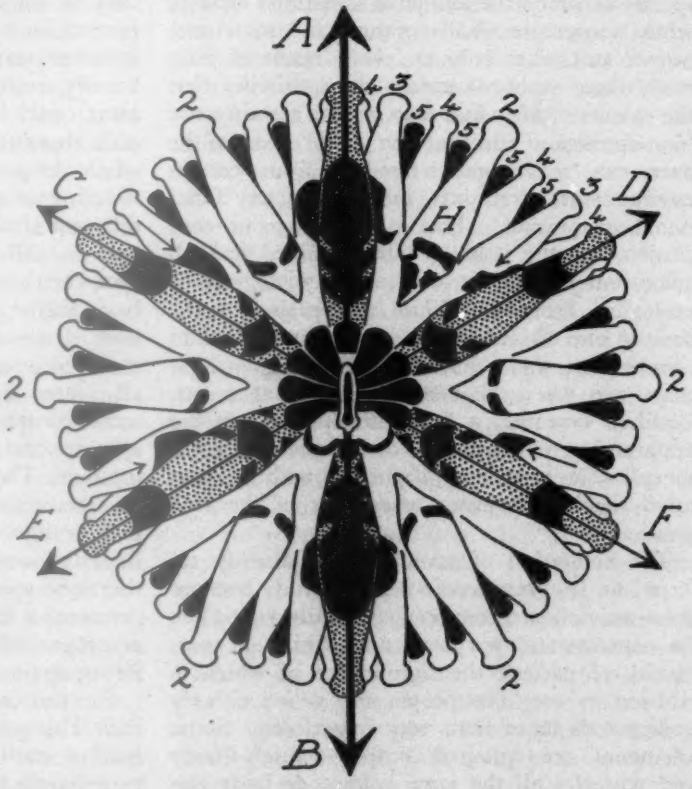


FIGURE 1 – *Diagram illustrating the bilateral arrangement of the pattern on the disc of a specimen of the sea-anemone* Calliactis parasitica. *The radial markings which, in the living animal, are carried out in opaque cream on a translucent ground, are here represented in black on a white ground. The six primary tentacles are stippled; the directive radii and mouth are also stippled, to indicate the directive axis. Only the four inner circlets of tentacles are included, and the circle to which each belongs is indicated by a number. It is to be noted that the six groups of pale markings are not centred about the six primary tentacles; on the contrary, while two of them (one larger than the other) are centred about the directive tentacles, the other four are centred about tentacles of the third series, and are symmetrically disposed with relation to the directive axis. The most conspicuous* individual *pale markings are not six but seven in number, and occur on six symmetrically disposed tertiary radii with the addition of the upper directive radius.*

(*Reproduced from* The British Sea Anemones, *by T. A. Stephenson, by kind permission of the Ray Society*)

FIGURE 2 – *Diagram emphasizing some of the features of the pattern on the disc and tentacles of the sea-anemone illustrated in plate IV.* AB = *directive axis;* C, D, E, F = *primary non-directive axes. Primary tentacles and radii stippled.* 2 = *secondary tentacle;* 3–5 = *tentacles of outer circlets, numbered in one sector only.* H = *a tentacle at the base of which the pattern is not normally developed. The four small inwardly directed arrows indicate patches of dark colour which are symmetrically placed with relation to the directive axis but are not symmetrical about the primary radii. Similar patches flank the directive tentacles. The small tentacles of the outermost (fifth) circlet do not occur all the way round the periphery (if they did there would be forty-eight of them, whereas there are actually twenty-four), but only in the part of each sector centring about a secondary tentacle: there was a departure from this rule only in one sector, in which there were two additional tentacles (not shown). Further explanation will be found in the text and on plate IV.*



(warm-temperate) part of their geographical range. On the northern part of the west coast of South Africa, where the water is colder, the pallid variety becomes dominant and the scarlet and violet ones scarce or absent. On the northern part of the east coast, where the water is subtropical, the bright colours again disappear and the specimens are all of dull reddish and greenish shades. In the case of the dog-whelks it has been shown by H. B. Moore that the pigments responsible for the pink and lilac, brown and black types of coloration are derived from mussels eaten by the whelks, and that these types are correlated in abundance with the proportion of mussels in the diet. These whelks also eat barnacles. The yellow coloration of other individuals was not shown to have any connection with diet but was suspected of having an indirect correlation with the degree of wave action to which the animals are exposed. Examples of the inexplicable type of coloration are given in the other two plates, and these are described in detail below. One which is not illustrated here, but which has been studied by Fox and Pantin, may also be mentioned. This is the sea-anemone *Metridium dianthus*, a large species in which the animal is sometimes entirely white, sometimes wholly orange, and sometimes brown and other colours. As a result of their study these authors consider the possibility that the colours of *Metridium* may be in a certain sense 'non-significant' and that 'the vivid colours of the anemones may signify freedom from certain environmental restraints, rather than any functional adaptation.' This is a courageous conclusion, because it is too often assumed that all coloration must have a direct physiological or ecological function. While this prejudges the issue in one direction, it is equally prejudicial to assume that there must be more in coloration than can be explained in functional terms. Possibly, however, a fuller investigation of the apparently non-functional, or at least at present inexplicable, types may, if pursued with an open mind, lead to a juster assessment of the true position.

The coloration of sea-anemones, already referred to, is a very fertile field for study because these animals are common, are easily kept alive for experimental purposes, and exhibit a complexity of pattern the significance of which is realized by very few people and which nobody understands more than very imperfectly. Some anemones are coloured simply enough—body and tentacles all the same colour, or body one colour and tentacles another, with no special markings. Others have a mosaic-like pattern of variously shaped and coloured markings which may be as elaborate as the design on a Persian carpet. Examples of such patterns are shown in plates I and IV. They have some very remarkable features. The anemone itself has a cylindrical body covered by a circular 'disc,' in the centre of which is the mouth; the peripheral part of the disc bears radiating tentacles. The disc also shows radiating lines which are all that is visible externally of the internal organs known as 'mesenteries.' These landmarks—a centre, radiating lines, and a circle—set the stage for the pattern. With strict relation to them, markings of various shapes are placed with mathematical accuracy. The pattern is by no means determined in its details solely by these visible landmarks, but is also related to invisible radii and concentric circles parallel with the visible ones. Each species of anemone has a particular pattern which is characteristic of it, but this pattern is merely a theme upon which many variations can be played. Just as a single pattern can be printed on material in different colours, so can the anemone pattern vary in colour. It is easy to see, also, that the pattern on a length of material could be varied in other ways. Some of its features could be heavily emphasized and others lightly indicated; some could be left out altogether; the shape of each element in the pattern could be varied; the whole thing could be speckled over with irregular stippling or modified by printing larger areas of different tints right across different parts of the pattern. All these devices are followed by individual anemones of the same species, using the same basic theme all the time. Sometimes an individual drops out the pattern altogether and is coloured in one or more uniform shades. Naturally these variations produce different effects, some conspicuous and startling, others inconspicuous and inclined to merge with their backgrounds. The situation is complicated by the fact that conspicuous individuals (e.g. blazing white and orange) and inconspicuous ones (e.g. an intricate mosaic pattern of browns) of one and the same species will occur under identical circumstances in the same pool; and these may be accompanied by pure white and bright pink forms, again belonging to the same species.

Has this coloration any value in the anemone's life? This question cannot be answered with any finality until far more field observations and experiments have been carried out than have yet

been made. There are indications, however, which make functional explanations seem rather unsatisfying or which suggest that, even if the explanation is partly functional, it is partly to be sought elsewhere. The coexistence in the same pool of individuals exhibiting 'warning' and 'protective' types of coloration has just been mentioned, and it must be remembered that some at least of the animals which eat anemones possess such limited powers of vision that there is no question of their being able to see the patterns as we do. Again, some anemones simulate their background (e.g. they may look like gravel), as do many land animals. This effect is easily achieved by a quite irregular, non-mathematical pattern with no relation to the structural landmarks of the animal; why then, if the simulation of gravel is the object to be achieved, should so many of the patterns exhibit so marked and precise a mathematical complexity when it can be done without any such elaboration? Moreover, in the group of anemones taken as a whole, there are far too many of these patterns. It is probable that several hundred anemone species exhibit complex patterns and that no two of them are identical; and some of them are remarkable to a degree. Probably the great majority render their possessors inconspicuous, but why is this done in so many mathematically different ways?

It explains very little to point out that as an anemone grows these patterns result automatically from the periodic deposition of pigment at various points in the tissues. This orderly growth, taken alone, should produce results, in different individuals of a species, of the same order of uniformity as regards colour patterns as it does for the details of anatomical structure. This does not happen at all. While a genetical analysis would illuminate the problem from some points of view, it would probably reveal the mechanism itself more fully than the reasons for it. It is a current view that if any variant of a species exists in a reasonable proportion of individuals it must necessarily be beneficial, at least in a great majority of cases. This view (e.g. 'if a form occupies even a small percentage of a population, it must normally have reached that frequency because it is beneficial') is well stated, for instance, with the reasons which have led to it, by E. B. Ford in his recent book, *Butterflies* (1945). The reasons are seductive and convincing, and the argument of this article is by no means intended to be set in opposition to them. Yet one has a feeling that just as our knowledge of the interaction of variation and natural selection is now a very different thing from what it was in 1900, the next fifty years may reveal further influences, as yet unsuspected or only partly known, which may make possible a modification of current theory in the direction of showing that variations which are neutral as far as their survival value is concerned play a larger part than is now supposed.

One thing about these patterns, however, is abundantly clear, and that is that they are related to certain structural axes of the animal in a much more fundamental and apparently inexplicable way than is generally realized; it is by following up this side of the picture that the most interesting progress might be made. Most anemones, when looked at from above the tentacular crown (as in plate IV and figures 1 and 2), are obviously radially symmetrical, and the radii, while following various numbers, most often occur in multiples of six, so that there are six chief radii, along which lie the six largest (primary) tentacles. Alternating with these are six secondary radii and tentacles, twelve tertiary ones, and so on, every species having its characteristic arrangement. There is, however, in nearly all anemones, a further axis, known as the 'directive axis,' which crosses the whole tentacular crown (passing through the slit-shaped mouth and along two of the primary tentacles), dividing the animal into halves. What this directive axis is, nobody knows; but it has been shown to be of fundamental importance in development, growth, and regeneration; and every structure, inside the animal and outside, is related to it. The result is that the symmetry represents an intricate fusion of a radial pattern related to the tentacles and mesenteries, and a bilateral pattern related to the directive axis. The coloration of disc and tentacles, like everything else, obeys this principle; and while it is not possible in this brief article to enter upon a detailed description of the patterns illustrated in plates I and IV and in figures 1 and 2, a close study of those figures will confirm what has just been said. The example shown in figure 1 (*Calliactis*) is peculiarly noteworthy, for we have here an anemone which, in the arrangement of its tentacles and mesenteries, is as neatly and regularly six-rayed as any anemone known; yet the pattern of cream-coloured splashes on its disc has little relation to the six-rayed basis, and is not only itself partly seven-rayed but is related with great precision to the directive axis.

The improvement of British grasslands and pasture

T. G. B. OSBORN

The proper maintenance of grassland depends ultimately on the skill and care with which the farmer manages his land, but the plant breeder is able to render very valuable assistance by producing new strains of grass suitable for specific localities and for various agricultural purposes. From the biological point of view the problem is an ecological one. This important fact was first clearly recognized and applied by Sir George Stapledon and his colleagues, to whom modern progress in grassland utilization is in large measure due.

Green fields and grassy hills are so characteristic a feature of the British landscape that many people are apt to forget that the grasslands are for the greater part made by man. They exist because man has learnt to maintain a collection of herbaceous plants which can survive and even flourish despite repeated grazing and cropping. Pasture is not a natural community of grasses and herbs in balance with the climatic factors and soil conditions: it is an assemblage of such plants together with the grazing animals which feed upon it.

The climax vegetation of Britain below 800–1,000 ft., and possibly even higher, is woodland. For centuries, and in the case of the Downs (the chalk uplands of southern England) from prehistoric times, the inhabitants of these islands have cut and destroyed trees to provide open areas for the growth of grass or crops.

How quickly and completely grassland may revert to woodland, even on long-cultivated arable land, is seen in the classic Broad Balk 'Wilderness' at Rothamsted. In 1882 Sir John Lawes ordered that a strip of land in full crop, running across the top of his experimental plots for wheat cultivation on the Broad Balk field, should be left unharvested to see what would happen. In four years the wheat had been entirely ousted by invading plants; today the area is a piece of oak woodland with the commonly associated shrubs and undergrowth.

There are many problems of grassland establishment, utilization, and improvement which await scientific help. The history of pasture improvement in Britain is a long one. Ryegrass was sown in the seventeenth century, and the introduction of Dutch clover, a form of the common British white clover (*Trifolium repens*), occurred only a little later. Sinclair's *Hortus Gramineus Woburnensis* (1824) records the experiments instituted by the then Duke of Bedford in 'the produce and nutritive qualities of different grasses and other plants used as food by domestic animals.' Even then certain species of grasses and clovers were recognized as suitable for use in permanent pasture, others on dry uplands, and others in alternate husbandry, a precursor of modern ley farming. The work of Robert H. Elliot at Clifton Park involved the use of seed mixtures of remarkable complexity in an attempt quickly to re-establish sown pastures that would be as valuable as first-class old permanent grassland. Some simplification of the seed mixtures, and in particular a recognition of the importance of wild white clover, was the contribution of Gilchrist as a result of his experiments at Cockle Park. The difficulty in these pioneering efforts was that the results were unreliable. The sown species disappeared and were replaced by the less valuable natural herbage of the district.

The modern progress in grassland utilization in Britain is due in large measure to Sir George Stapledon and his colleagues. He has always insisted that the problems involved are primarily ecological. Progress in plant genetics, which has led to the breeding of special types of grasses and clovers, has given the modern grassland farmer a far greater quantity of suitable plant material with which to build up his sward than had his predecessors even twenty years ago. In the end, however, it is only by an understanding of the ecology of the constituent species and of the sward which they form that the artificial community can be maintained.

The grasslands of Britain may be divided into three categories: the rough grazings, the permanent grasslands, and lands under temporary grass. The latter are known as leys. The rough grazings generally lie at high altitudes. Many are important grazing grounds for sheep or cattle, and

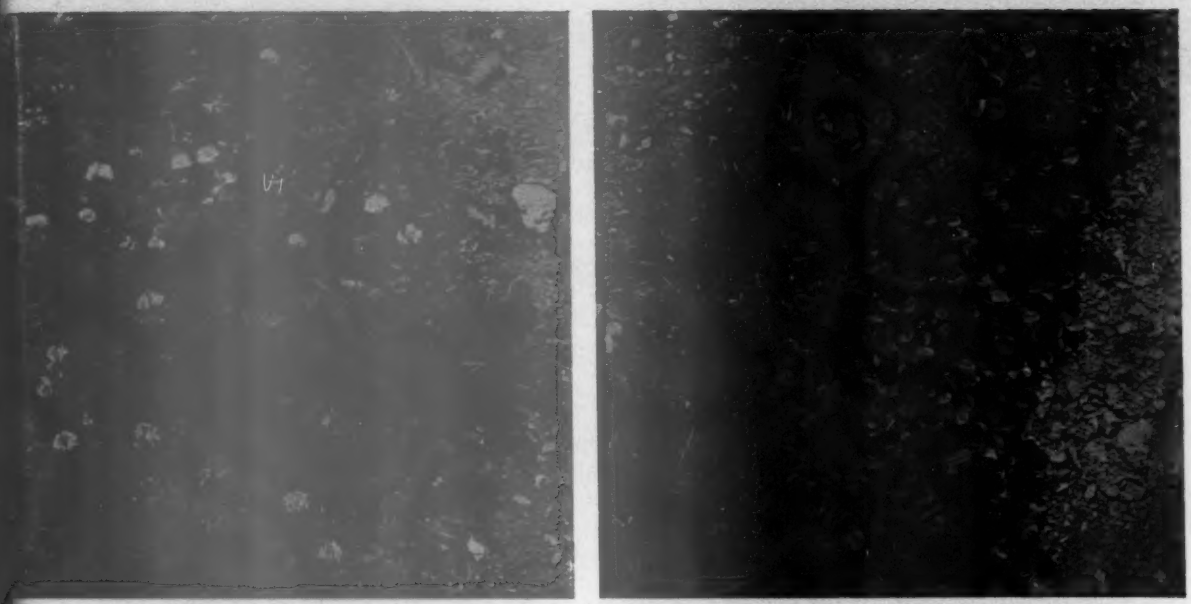


FIGURE 1 – *Aberystwyth strains of wild white clover,* Trifolium repens, *S*100 (*left*) *and S*188 (*right*). *The more erect leafy habit of growth and later flowering of the strain S*188 *are evident.* (*Reproduced by courtesy of the Director of the National Institute of Agricultural Botany, Cambridge*)

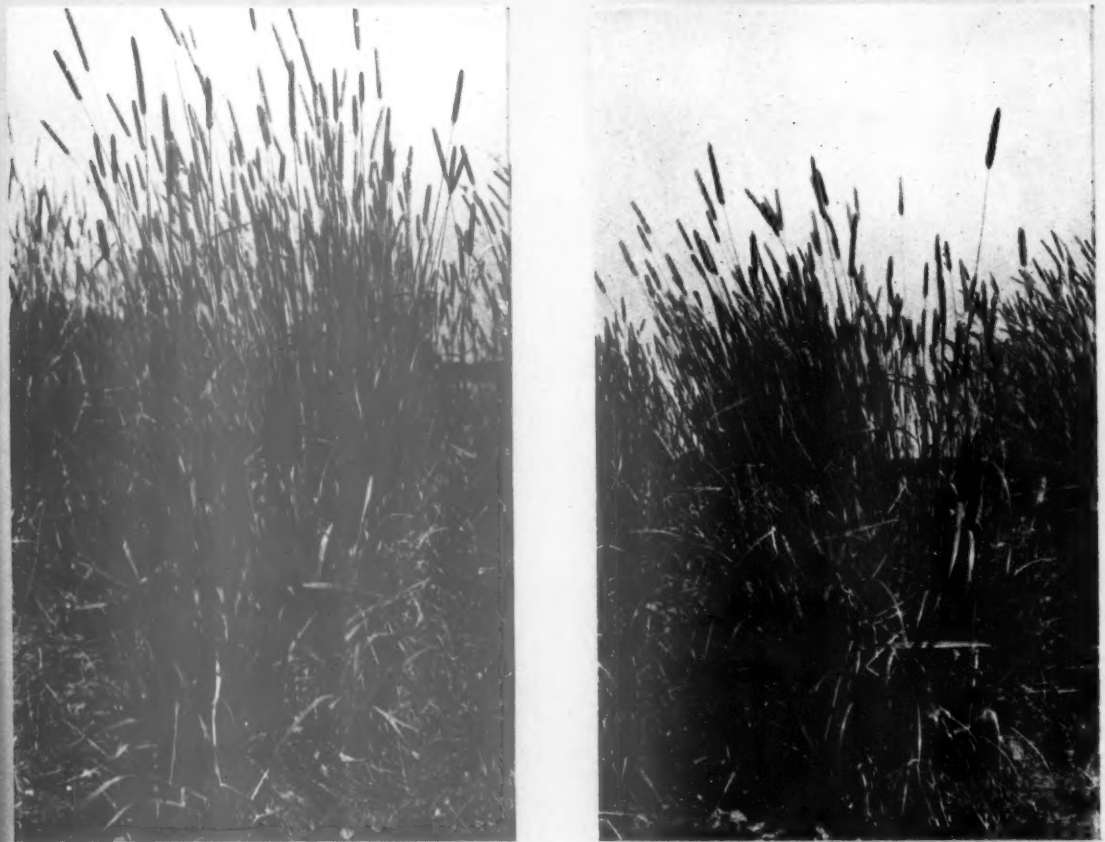


FIGURE 2 – *Two strains of timothy grass,* Phleum pratense. *On the left is a commercial hay type of timothy grass, showing tall stems and relatively few leaves. On the right is an improved hay type of timothy grass, with considerably increased foliage, thus giving greater weight of nutritious fodder.* (*Reproduced by courtesy of the Director of the National Institute of Agricultural Botany, Cambridge*)

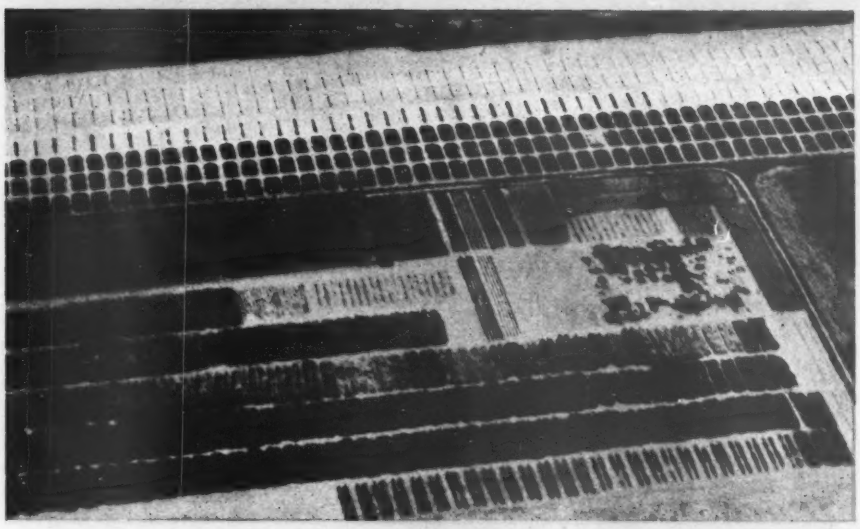


FIGURE 3 – *Aerial photograph of plots of grasses and clovers, National stitute of Agricultural Botany, Cambri*
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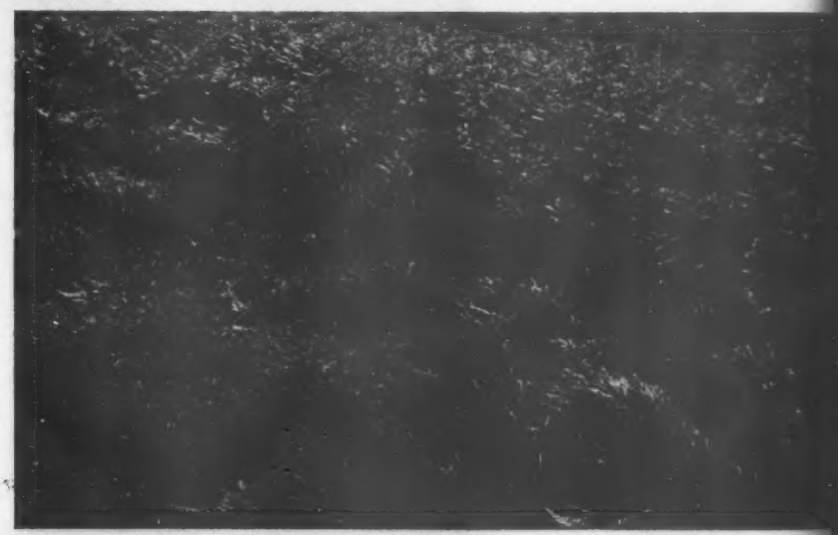

FIGURE 4*a* – *Unimproved natural vegetation of the Welsh hills, showing growth of bracken fern* (Pteridium aquilinum), *gorse* (Ulex nana), *and coarse non-nutritious grasses.* (*Cahn Hill Improvement Scheme.*)

FIGURE 4*b* – *Neighbouring field improved pasture after ploughing, tr ment with fertilizers, and sowing pas grasses with wild white clover.* (C Hill Improvement Scheme.)

their due utilization plays an important part in the national economy. Many of their problems are economic, as must always be the case with marginal lands. Their importance to the country may be realized when it is remembered that in England and Wales they have an area of about five million acres, roughly one-sixth of the total agricultural area of the two countries. In Scotland more than ten million acres are classified as 'mountain and heath land for grazing.' There is no doubt that considerable improvement of the grazing of many hill pastures is possible, with consequent improvement of their carrying capacity. The Cahn Hill Improvement Scheme, started in 1933 in association with the Welsh Plant Breeding Station, has done valuable pioneer work in this direction.

Permanent grass includes fields which are either grazed or mown for hay, or both. In 1939 it covered more than fifteen million acres of England and Wales, and though the area has been considerably reduced as a result of the policy of bringing more land under the plough, it still occupies nearly half the agricultural area of the two countries. Permanent grasslands contain mixed assemblages of different grasses, clovers, and other herbs, and their value varies enormously. They all have this ecological feature in common—they are in a state of unstable equilibrium. Man controls the incidence of the biological factors by his systems of management, an art far older than the recognition of the scientific principles upon which it is based.

Revolutionary changes in the composition of a sward can be obtained by the application of various combinations of manures. The action of nitrogen in stimulating the growth of grasses, with a reduction in the amount of clovers, is well known. But, as Blackman [1] has shown, the effect on the clover may be due to competition for light.

The bulk of the permanent grassland in Britain has been built up over a period of time by unconscious selection from the indigenous plants of those species that fit particular niches in its composition. Ability to grow and reproduce under conditions of defoliation and trampling is essential for the survival of the plants composing it. Man, who determines the very existence of the assemblage of plants, can control only such things as at what season of the year, how frequently, and for how long the plants shall be required to submit to grazing and how severely they shall be punished in the process. By unskilful management, for example overgrazing followed by undergrazing, the growth of weeds and thistles will be encouraged [6]. The finest old permanent grasslands of Britain, such as occur in Leicestershire and in the Weald of Kent, contain an assemblage of plants built up in the course of time by the selective effect of this biological factor. The desirability of using grass seeds obtained from old pastures was noted by Sinclair as long ago as 1824. It was not till nearly a hundred years later that Stapledon began to accumulate his collections of cocksfoot and Jenkin his collections of ryegrass, including many from old pastures, that were to play such an important part in the building up of the Aberystwyth strains.

The temporary pastures are the short- or long-term leys—fields sown to either a single grass or clover species or to a simple mixture, grown for a time, and then ploughed in preparatory to a cycle of arable crops. The best modern usage, which in some respects is a return to the methods of alternate husbandry, would give a long ley a life of four, six, or eight years before it is ploughed in again. The problem in laying down such a ley has been to select such an assemblage of grass and clover species as will produce, within a season or two, a sward that will stand up to grazing or hay-cutting, or both, as successfully as one that has been built up by careful management over a period of time. What species should be grown, whence should the seed be obtained, and in what proportions should it be mixed in order that, during the stages of germination and subsequent competition between the mature plants, the sward will persist as a close-growing ground cover capable of being grazed or mown [2], [7]?

The problems that are involved in producing the seeds of pasture plants are very different from those affecting seed for cereal crops such as wheat. Cereals are normally self-fertilized; the desired hybrid variety having been raised, its multiplication is a relatively simple matter, since there is little fear of contamination by pollen from other varieties. On the other hand, most of the perennial grasses, as well as the important red and white clovers, are normally cross-pollinated. Indeed, a high degree of self-sterility exists among them. It follows, therefore, that a considerable amount of variability occurs in any natural population as a result of gene-exchange. The individuals in such a population may differ among themselves in a variety of ways. Some of these differences depend on physiological characteristics such as earliness or lateness of vegetative growth, season of flowering, and so on. This

minute variability is acted upon by the environment in a freely interbreeding population of any species. In this manner ecotypes may arise.

It was in 1922 that Turesson [8] first published an account of his observations and experiments on several species of common plants occurring wild in different habitats and in different parts of Sweden. As a result he was led to formulate his conception of the ecotype as 'an ecological unit to cover the product arising as a result of the genotypical response . . . to a particular habitat.' The conception of the ecotype has stimulated ecological and genetical work over a wide field and has led to important conclusions as to the nature of species [4], [9]. The practical importance of the ecotype conception for grassland work has also been great. Viewing the problems of sown grass in the light of it one is tempted to think that, ideally, the different kinds of grasses and clovers required in a particular district or country should be developed locally, since only in this way can the full selective effect of the local environmental factors be obtained.

Stapledon records that in 1918, when making a tour of the grasslands of England in connection with work for the Ministry of Agriculture, his attention was drawn to the extreme variation in form to be observed between plants of cocksfoot (orchard grass), *Dactylis glomerata* [10]. Returning to Aberystwyth, and using the facilities afforded by the Welsh Plant Breeding Station, which was founded in 1919 by Lord Milford, he and his colleagues began an extensive study of grasses and clovers of agronomic importance. Stapledon concentrated his attention on cocksfoot. More than three hundred individual plants were dug up from representative habitats in Britain. Seed was obtained from Europe, the United States, and New Zealand. In all, over eleven thousand individual plants were brought under critical study. Some, because their erect-growing leafy shoots mingled with the flowering stems, were highly desirable for hay crops; others, because of their spreading habit and free tillering, were more desirable for pasture.

Work on other species—notably ryegrass, *Lolium perenne*—was directed by Dr (now Professor) Jenkin. Controlled breeding experiments showed that self-pollinating races could be obtained, but that in most cases such inbreeding had undesirable results. The decision was therefore taken to build up strains of interbreeding plants. A strain is not a homogeneous self-pollinating race; it is a mixture of races, cross-pollinating and showing a combination of characteristics desirable for the purpose for which it is produced [5]. Thus S23 (all the Aberystwyth strains are known by numerals preceded by the letter S) is a densely growing, leafy, late-flowering type of ryegrass persistent in pastures on good soils. It was derived from plants obtained from very old grazed pastures in the Midlands, Kent, Lincolnshire, and even Holland. S24, on the other hand, is primarily based on two ryegrass plants found in the wild state but not on grazed pasture. With their progeny, plants from New Zealand have been incorporated. The result is an early-flowering, leafy hay strain. A strain is as much a product of the breeder's art as of his scientific knowledge.

Having built up a desirable strain, the production of sufficient seed for the market demands constant scientific supervision [3]. Isolation of the growing stocks from other fields containing different races of the same species is obviously essential. Pasture and hay strains of the three main species of agronomic grass—cocksfoot, ryegrass, and timothy—have been built up at Aberystwyth and at the Scottish Plant Breeding Station at Corstorphine. With these and the appropriate strains of red and white clovers [11] the production of grass fields suitable for particular purposes and at particular seasons of the year can be undertaken with a feeling of assurance impossible even ten years ago.

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The evolution of locust control

O. B. LEAN

Since prehistoric times plagues of locusts have been feared as the forerunners of famine and suffering. For centuries man's only defence has been the destruction of the pest at the points of its immediate onslaught—a task hopelessly beyond the strength of small and isolated communities. Today, knowledge of the breeding and migratory habits of locusts has made it possible to locate the source of potential new outbreaks, and chemical methods are being used to destroy the pests before they can begin their destructive activities.

The foundation of modern locust control was laid in 1921, when Uvarov first propounded, as a working hypothesis, his fundamental phase theory. Before that date intensive anti-locust campaigns had been waged in the more advanced countries liable to periodic attack, but it is only since 1921, and particularly since 1938, that the campaigns have been planned intelligently with the purpose of preventing locust invasions of rich agricultural lands rather than as a last-minute defence of the crops. This change of policy from defence to aggression became accentuated during the war years, when the vital importance of protecting foodstuffs stimulated anti-locust efforts in an unprecedented manner.

In an earlier article in ENDEAVOUR, Imms[1] described the bionomics of so-called locusts. The latter is no precise systematic term but is used to describe those short-horned grasshoppers which may develop both gregarious and migratory habits. There are about eight kinds of true locust, with several sub-species and geographical races invading over eighty countries in Europe, Asia, Africa, the Americas, and Australasia. Though varying greatly in their habits and ecology, the phase theory appears to apply to all.

The locust species are extremely plastic in their morphological characters and behaviour, and the extreme forms may be so different that they were once regarded as distinct species. These forms are named the phases. At one extreme the individuals of *phase solitaria* behave as relatively inactive, solitary grasshoppers, exhibiting little reaction to the presence of their fellows. At the other extreme the individuals of *phase gregaria*, the true locust, possess highly developed gregarious and migratory habits which lead the immature stages to march in massed hopper bands and the adults to migrate long distances in dense swarms.

[1] 'Locust Invasions and their Control,' ENDEAVOUR (1943), II, 56.

The phase of a locust community depends upon population density. Thus a considerable number of *solitaria* hoppers developing in a restricted environment may become true locusts. Conversely, a few hoppers of true locusts developing in an unconfined space may revert to grasshoppers.

This is the barest outline of the phase theory, but it is of essential importance because the high policy of locust control depends upon its implications, just as the strategy of regional campaigns depends upon the seasonal cycle of the locust and the tactics of the separate battles upon the daily regimen of the hoppers or adults.

PREVENTIVE POLICY

Though entomologists of several countries have attempted to prove that locust outbreaks occur at regular intervals—usually in 11–13-year cycles—the data do not substantiate such a mathematical rhythm.

The sequence of events which initiate a locust outbreak are less obscure than the details of the ecological relationships which actually cause the transition of the phases. The solitary phases of several locust species are widely distributed, but it is only in certain limited localities, called outbreak areas, that favourable conditions may cause a concentration of population leading to gregariousness and the production of the swarming phase.

The solitary phase of the African Migratory Locust, *Locusta migratoria migratorioides* (R. and F.), is distributed throughout Africa, all Europe, and Asia south of latitude 60°. Swarms invade nearly all tropical Africa. In 1929 I witnessed swarms pouring into Nigeria, and such was the state of our knowledge eighteen years ago that this invasion came unannounced and its origin was not discovered until the swarm movements of the whole outbreak had been analysed. We now know that the original transition of *phase solitaria* into *phase gregaria* took place in 1928 within an area of seven

thousand square miles among the swamps of the river Niger in the French Sudan. From this single focus swarms spread, generation by generation, during the subsequent nine years, until they covered ten million square miles of Africa. In British and French West Africa, Equatorial Africa, the Sudan, Eritrea, British East Africa, the Belgian Congo, and the Rhodesias costly campaigns were improvised to destroy each generation of hoppers, but in spite of all efforts the plague lasted until 1937 and crop losses were considerable.

The basic policy for the control of the African Migratory Locust became clear with the discovery of the Middle Niger outbreak area, even though it may not be the only potential danger spot. By controlling any undue multiplication of *solitaria* populations the development of *phase gregaria* and migratory swarms could be prevented.

The war interrupted the establishment of an international organisation as recommended at the Fifth International Locust Conference held in Brussels in 1938 to study the outbreak area, to keep it under continuous surveillance, and to eliminate any incipient swarming. The French, however, acting alone, founded a preventive service which has kept the zone under observation since 1939.

The control of the Red Locust, *Nomadacris septemfasciata* (Serv.), has progressed one stage farther. During the period 1930–8 entomologists of many nationalities dispersed into the interior of Africa and of western Asia and they returned with many discoveries. One of the most important was the demarcation of outbreak areas of the Red Locust on the Shores of Lake Rukwa in Tanganyika and the Mweru marshes on the borders of the Belgian Congo and Northern Rhodesia. An Anglo-Belgian control service was set up in 1941. The headquarters are in a British colony and the Director is a Belgian entomologist. As the Red Locust invades nearly the whole of Africa south of the Equator and some countries farther north, about eighteen territories benefit from this localized preventive policy.

The permanent prevention of the Desert Locust, *Schistocerca gregaria* (Forsk.), is a more complex problem that has yet to be similarly tackled. This is the most widely spread of all the locusts, as it ranges from Senegal and Morocco in West Africa to central India, and from Turkey and southern republics of the U.S.S.R., through the Arabian Peninsula, to Tanganyika Territory. Some outbreak areas are known, others are suspected, and it is clear that the plagues may develop from several widely separated areas in a manner somewhat different from the original conception of phase transition. Although preliminary aggregation may occur within definable limits, swarm formation may, with this species at least, be a more gradual process involving the migration of *solitaria* or intermediate forms from one seasonal breeding area to another, normally between zones of winter and summer rainfall. Areas such as the Mekran coast and both coasts of the southern Red Sea, where two climatic systems adjoin, are most dangerous, but the problem is greatly complicated by the irregular rainfall over much of the desert country inhabited by this species.

The establishment of an international preventive service was recommended at the Brussels Conference, but again the war intervened and at the same time a new outbreak of this locust, which began in 1940 and still continues, distracted thought from prevention to the more immediate problem of positive action against invading swarms. During the past seven years the Desert Locust has invaded over thirty territories, and the very high costs of the anti-locust campaigns—a total not computed but probably at least £15 million—has again focused attention on the need for international action and a policy based upon stopping swarm formation at the origin.

Unfortunately the picture is not clear-cut. Recent studies have clarified our ideas on the Desert Locust but much remains to be investigated. When an international body is formed its first duties should be scientific exploration to identify the danger areas and to elucidate all the ecological factors which may lead to the development of *phase gregaria*.

Turning to the New World, we find a similar problem. The South American locust, *Schistocerca cancellata* (Serv.), is best known in Argentina (which suffers more than any other country in the world from locust plagues), Uruguay, and Brazil; but it also attacks Bolivia, Paraguay, and Chile. Outbreaks in the north, in Peru, Ecuador, and Colombia may be linked with the southern activity of this species or may be independent.

Information on the South American locust is still fragmentary, largely because swarm movements have been studied only territorially. Yet again the necessity for international co-operation is recognized, and at a conference held in Montevideo in September 1946 representatives of nine states recommended the creation of a permanent Pan-American preventive organization.

A somewhat different but allied question is the

4 Days

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FIGURE 1 (*above*) – *Hopper of the Desert Locust,* Schistocerca gregaria. (× 1½)
(Reproduced by permission of the Anti-Locust Research Centre, British Museum.)

FIGURE 2 (*top right*) – *The African Migratory Locust,* Locusta migratoria migratorioides. (× 1½)

FIGURE 3 (*right*) – *Mountain country of south Iran, typical of the country in which locust control work has to be carried out.*

FIGURE 4 – *A pool of young hoppers, Eritrea.*

FIGURE 5 – *Maize stripped by hoppers, Argentine.*

FIGURE 6 – *Flame-throwers in action, Eritrea.*

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control of the Moroccan Locust, *Dociostaurus moroccanus* (Thnbg.), a Mediterranean species that extends from Spain and Morocco through southern Europe and Anatolia to Transcaucasia, Iran, and Afghanistan. This species is not migratory to the extent of the other locusts already discussed. Yet the factors responsible for swarm formation throughout its area of distribution are probably similar, and a practical preventive policy can be evolved only through centralized research.

SEASONAL STRATEGY

Each year during an outbreak swarm migrations and breeding follow a similar pattern. When locust swarms migrate from one country to the next and from continent to continent they are carried by the climatic tide. Locust species vary in their habitats and in their response to climate and eco-climate, but none can live or breed in extreme wet or dry conditions or in extreme temperatures, and the migrations help the species to avoid adverse environments.

The Anglo-Egyptian Sudan and the highlands of Eritrea have a tropical climate with a single rainfall maximum during the summer; the Desert Locust breeds throughout this climatic zone approximately from June to October. With the onset of the dry season swarms of the next generation are carried north-east to the Red Sea coast and more especially into Arabia, where the rains fall in winter. The Desert Locust also breeds during monsoon rainfall in north-west India, whence the young swarms fly westwards to the regions of winter rainfall around the Persian Gulf. Some may breed in south Iran, some across the Gulf in Arabia, and some may travel as far as Iraq—a flight of 1,200 miles.

The Arabian swarms bred during the winter and spring migrate generally north and west to invade the Euphrates valley, Syria, Palestine, and the Nile delta. The Iranian swarms of the same generation fly north into central Iran and sometimes as far as Russia. In all these regions breeding takes place during the late spring and the swarms of the next generation return to summer rainfall areas, the Iranian swarms to India and the Egyptian-Syrian-Iraqi swarms back towards the Sudan.

Arabia and south Iran are key dispersal areas during seasonal outbreaks, and though they are not agricultural districts it becomes worth while to attack the hoppers there in order to minimize any subsequent invasion of richer lands.

During the war British specialists, basing their strategy upon newly acquired knowledge of this cycle, accepted the major responsibility for these arduous and novel campaigns. Before the first reconnaissance of the interior of Arabia in 1942 such operations would have seemed impracticable, but by 1944 a complex organization had been built up, with motorized baiting parties penetrating practically the entire breeding area. In Arabia the British Middle East Anti-Locust Unit was assisted by Egyptian and Indian parties and by workers from the Sudan and Palestine; in Iran the British unit worked alongside Iranian, Russian, and Indian missions. Such international co-operation in the field was something entirely new.

Knowledge of the South American locust lags behind that of other species. Nevertheless we know that Uruguay receives its swarms from or through Argentina and that during spring the voracious immature southern swarms cross the western frontier to invade an agricultural belt. The best defence of Uruguay may lie hundreds of miles away, but until the origin of the swarms is certain they should be destroyed immediately they cross the frontier. The defence of the 270-mile frontier will prove difficult indeed, and the mobile swarms can possibly be best attacked from aircraft.

There is a popular but erroneous impression, fostered by publicity, that aircraft are the latest answer to the locust. Aeroplanes have been employed for many years, but mostly for speeding up operations that can be pursued from the ground. The real use for aeroplanes would seem to be against flying swarms, against which there is no other reply.

Air offensives are bound to be costly, and their future is likely to depend upon developing an extremely toxic contact insecticide—something comparable to 'Gammexane,' killing at a few grams per acre in bait. A fair-size locust swarm may measure 20 miles by 2 miles, covering 25,600 acres. At a dosage of half a gallon (5 lb.) per acre, of liquid insecticide, about 60 tons would be expended. A fleet of aircraft, requiring many people for maintenance, would be needed.

To destroy a few swarms by such means is not enough, but air spraying may become economic when it can prevent a widespread invasion of a country, thus saving the aggregate cost of damage to crops and of hopper campaigns, and if considerable reduction of dosage can be gained by improved technique, as seems possible from recent British research. The protection of Uruguay is a possible application, but even better would be the defence of some defile through which a seasonal migration is directed and where aircraft can

strike at the swarms as they pass. While research on these lines proceeds, spraying from the air remains no more than a future possibility.

It is a mistake to conceive any anti-locust campaign as a set-piece. Early preparations demand a plan, but this must be flexible, and all units must be mobile. Battle headquarters, watching the trend of the locust invasion through daily radio reports from its detachments, will frequently require last-minute adjustments in the disposition of its forces to meet a changing situation. In 1945–6, for example, breeding in Arabia occurred exceptionally far north, and much of the area was out of reach of the detachments placed to meet a normal invasion.

No account of modern locust control would be complete without acknowledgment of the pioneer work in this direction of the Anti-Locust Research Centre of London. This British institution, recognized since 1930 as an international co-ordinating, advisory, and forecasting centre, has been the inspiration behind all recent developments and has provided the data upon which many operational plans have been built. The Centre forecast the present outbreak of the Desert Locust, and for the first time in history threatened countries were warned to prepare their defences. In the territorial anti-locust headquarters, whether at Baghdad, Nairobi, Teheran, Jedda, Damascus, or Asmara, one can examine current situation maps plotting swarm movements, oviposition, and hopper infestations, and all these are pieced together by the Anti-Locust Research Centre to build up the entire picture. Each country consolidates its local reports and telegraphs a fortnightly summary to London and to its neighbours, following up with detailed swarm lists. All records are scrutinized, tabulated, and entered on large-scale maps. The Centre circulates in return a monthly situation summary and forecast of probable developments. No rigid system can serve all needs, and reports come in from all manner of sources. These reports may be too delayed to be incorporated in current summaries, but they help the Centre in its fundamental study of migrations, and these studies will shape future locust policy and strategy. During the past sixteen years the Anti-Locust Research Centre has dealt with about 8,000 swarm lists, corresponding to perhaps 100,000 individual swarm records.

DAILY TACTICS

In early history the farmer relied upon charms for protection, and even as late as 1942 Koranic prayers were hung from poles among the Iranian crops. Hoppers have probably been beaten and burnt since earliest times, and even today such crude methods—rarely effective and always extravagant in man-power—are all too common. Then perhaps came trenching, with encircled hopper bands being driven into pits or trenches by armies of men, and though this technique involves much labour it has been widely used during the present outbreak of Desert Locust, particularly in India.

The introduction of metal barriers as a refinement of simple trenching marked a definite advance, and the method became extremely popular. It is still employed, for instance, in Syria and South America—Argentina alone possesses 20,000 miles of barrier. When an advancing band reaches the barrier the hoppers, turning to right or left, eventually fall into carefully constructed pits or corrals from which they cannot escape. The method is at best cumbersome and lacks mobility.

Flame-throwers—the modern equivalent of simple burning—were first used on a campaign scale in Palestine in 1918. They are so spectacular that their popularity, in spite of their inefficiency and high working costs, dies slowly, and during the past few years they have been employed in Eritrea, Tripolitania, and South America, with Argentina again in the lead with about 50,000 hand machines.

Chemical control began when hoppers were sprayed or dusted with a great variety of crude contact insecticides such as kerosene, crude oil, and caustic soda, and when vegetation upon which hoppers were feeding was treated with arsenicals. Modern chemical control dates from the introduction of poison bait, and the technique remains the basis of all modern campaigns.

Poison-baiting succeeds because locusts, particularly in the hopper stages, are more attracted towards certain substances than to their normal food plants. A contact poison must hit each insect, but locusts seek out poison bait and their own destruction. Bait consists of an attractive edible base or carrier and a stomach insecticide. A great variety of bases has been used. The earliest was chopped green vegetation, then came dung, and though bran is now the popular choice many other materials such as sawdust, chaff, oilseed residues, bagasse, ground millet stalks or maize cobs, and coffee parchment are suitable. The choice of carrier should depend upon local availability, with waste products preferred to animal foodstuffs. Whatever the material, its effectiveness

depends largely upon the amount of water it will absorb and the slowness with which it dries out, as moisture is the principal cause of attraction.

The question of the poisonous ingredient is more important. Various arsenicals, particularly sodium arsenate, have been the most popular, though in some areas, including the United States, where there was a risk of poisoning domestic animals, sodium silicofluoride was favoured. Up to 1944 the commonest bait formula was 100 lb. dry bran, 1·5–2 lb. sodium arsenate, and 10 gallons water.

The introduction of benzene hexachloride as a bait poison in 1944 marks another milestone in the evolution of locust control. The principles of baiting remain unaltered, but two properties of the new poison have unlocked new doors. As it is non-toxic, in normal dosages, to higher animals, the new bait can be applied with complete confidence. This has permitted the introduction of locust control into the more backward countries where one fatal accident with sodium arsenite would have roused antagonism. It has accomplished a revolutionary change of attitude in the cattle-raising countries of South America, which are now turning to poison-baiting in place of more antiquated methods. Secondly, benzene hexachloride kills so quickly that the baiter is encouraged by seeing results within a few minutes.

The toxic component of benzene hexachloride is the γ-isomer, Gammexane. A standard bait contains 0·5 per cent. benzene hexachloride or about 0·065 per cent. Gammexane. From skilled hands 5 lb. of bait can, under good conditions, destroy an acre of hoppers. This means that less than 2 grams of the insecticide itself are applied per acre to kill perhaps five million insects. Only the experienced baiter, however, will kill an acre of hoppers with 5 lb. of bait. Bait itself is not expensive, but when it is shipped and then transported perhaps five hundred miles across the desert costs mount rapidly and strict economy becomes necessary.

The daily regimen of hopper behaviour, like the seasonal behaviour of swarms, is a cyclical series of responses to climate—eco-climates rather than regional climates. At low and high temperatures hoppers are immobile. At intermediate temperatures only slight fluctuations determine whether they feed without marching, feed while marching, or march without feeding. The line of march is not haphazard but orientated at least by wind direction, light, radiation, and topographical features. The locust-baiter can only gradually learn to expend his ammunition advantageously.

No single control method can, however, meet the diverse demands of locust control, and field techniques must vary and be as flexible as the entire anti-locust organization. Within recent years campaigning against the Desert Locust alone has been carried out under a bewildering variety of conditions. In Iran, 9,000 ft. up in the central plateau among a peasant farming community; in Syria, in the rich irrigated gardens around Damascus; in Transjordan, among the barren foothills of the mountains of Moab, a thousand feet below sea-level; in the Sudan, within the irrigated cotton-fields of the Gash delta; in the highlands of Abyssinia; in the empty deserts of Arabia; in Kenya, in the European highlands and the sparsely populated Northern Frontier Province; along the torrid coastlands of the Red Sea; down the wadis of the Hadramaut; beside the fertile Nile valley. Where water is scarce a dry bait can be used with success, and under similar conditions dusting with a contact poison may cease to be uneconomical.

Whatever the technique employed, simplicity of equipment and mobility favour effective kills. This is why poison-baiting has won its place as the leading method of control. Spraying or dusting machines, flame-throwers, or any other mechanical device give endless maintenance troubles.

ORGANIZATION

The spirit of international co-operation was fostered in various international conferences, but, although these are unavoidable and indeed necessary, real progress has resulted more from friendly and not too ritual exchange between the experts. Locust killing is skilled work and should be the responsibility of entomologists.

Locust infestations cannot be compared with attacks by less mobile insect pests, and locust control is accepted more and more as a government responsibility for the benefit of the community. This is in line with the need to develop broad research projects and to attack the locust wherever it can be reached, however far from cultivation. To pass responsibility from the farmer to the government is one stage, but units even larger than the individual country are required to oppose the locust successfully.

When the government takes over, operations can be planned scientifically, and the most successful present-day campaigns are run by self-contained locust control units. From his headquarters the entomologist in charge directs the operations to meet the ever-changing situation.

Nitrogen fixation by blue-green algae

G. E. FOGG

The ability of certain bacterial species to fix atmospheric nitrogen has been known since the end of the nineteenth century and was discussed by Professor Quastel in the previous issue of ENDEAVOUR. Only recently, however, has it been proved that some species of blue-green algae are also able to fix nitrogen. Although this process is of little agricultural value in the soils of temperate countries it appears to be of great practical importance in certain tropical soils, such as the ricefields of India, and in maintaining the productivity of fresh water.

There can be little doubt that the capacity to utilize the free nitrogen of the atmosphere in the synthesis of cell material, a capacity possessed by a small minority of living organisms, plays a very considerable part in maintaining the fertility of the earth [1]. Whereas the importance of *Azotobacter* and of leguminous plants in this respect is recognized, a third group of organisms able to fix nitrogen, the blue-green algae, has received less attention. However, our knowledge of nitrogen fixation by the organisms forming this group, although still meagre, is beginning to increase sufficiently for an idea of their possible importance to be obtained.

The blue-green algae, or *Myxophyceae*, are primitive plants having certain resemblances to the bacteria, for example in undergoing no sexual reproduction and in the absence of a nucleus of the type found in higher animals and plants. In the order *Chroococcales* the individuals are unicellular and may occur singly or aggregated into colonies, for example in species of *Gloeocapsa*. Members of the more evolved orders, *Nostocales* and *Stigonematales*, are filamentous, for example *Petalonema*, *Anabaena*, and *Gloeotrichia*.

That some of these algae are able to fix nitrogen was first indicated by the work of Frank [2] published in 1889, four years before the first isolation of a nitrogen-fixing bacterium by Winogradsky. Frank's cultures were, however, impure, and the first pure cultures of algae which became available were found unable to grow in the absence of combined nitrogen. As a result it was generally assumed that algae, including blue-green algae, are unable to fix nitrogen, and that where they develop in the apparent absence of combined nitrogen it is because of association with nitrogen-fixing bacteria. This opinion prevailed until comparatively recently, plausibility being lent to it by the isolation of nitrogen-fixing bacteria from algal material [3]. The main difficulty in proving nitrogen fixation by blue-green algae attends the preliminary step of obtaining cultures free from other organisms. Pure cultures are necessary because even if contaminating organisms are known to be unable to fix nitrogen alone, the possibility cannot be precluded that they are able to do so in association with the algae. The gelatinous sheath with which most members of this group are invested provides a natural medium for the development of bacteria and renders their removal by ordinary culture methods exceptionally difficult.

The first well-substantiated claim for nitrogen fixation by blue-green algae was put forward in 1928 by Drewes, and was based on work with pure cultures obtained by a laborious method of subculture [4]. Since then new methods for obtaining pure cultures have been evolved, the most convenient appearing to be that using ultra-violet light, a suitable irradiation killing the bacteria but not the algae [5, 6]. Recent workers have paid particular attention to checking the purity of their cultures [7, 8], and there can now be little doubt that really pure cultures have been obtained. Conclusive proof of fixation by a given species requires not only the use of pure cultures but a reliable method of demonstrating an increase in combined nitrogen. In the majority of studies on algae the Kjeldahl method for the estimation of nitrogen has been employed. Its use in work of this sort is open to criticism [1], but in cultures in a medium initially free from combined nitrogen, such as have most commonly been used, the objections that have been advanced do not apply. Recently, nitrogen fixation by *Nostoc muscorum* has been demonstrated by the use of the heavy isotope of nitrogen as a tracer element [9]; this provides confirmation of the validity of the more generally used method.

There is now satisfactory evidence of the nitrogen-fixing powers of the following species of blue-green algae: *Nostoc punctiforme* [4, 6, 10], *N. muscorum*

[9, 11], *N. paludosum* [6], *Anabaena variabilis* [4, 5, 6, 7], *A. gelatinosa* [7], *A. naviculoides* [7], *A. humicola* [6], *A. cylindrica* [6, 8], *A. ambigua* [12], *A. fertilissima* [12], *Cylindrospermum licheniforme* [6], *C. maius* [6], *C. gorakhporense* [12], and *Aulosira fertilissima* [12]. All these species belong to the same family, the *Nostocaceae*. Only further work can decide whether nitrogen fixation is confined to this one family, but meanwhile it is interesting to speculate on the possibility of other blue-green algae possessing the property. The known nitrogen-fixing algae may be exclusively *Nostocaceae* simply because members of this family are somewhat easier to culture than the others. The majority of blue-green algae have still to be investigated from this point of view. There is no lack of indications that species other than *Nostocaceae* may be able to fix nitrogen, and often they are found growing vigorously in environments very poor in combined nitrogen. Claims that species of *Oscillatoriaceae* and of *Chroococcales* possess the property have been put forward [13, 14], but in these cases there is no adequate evidence of the purity of the cultures used. Reports of blue-green algae found not to fix nitrogen are scanty, possibly because there is little incentive to publish such results.

Nitrogen fixation occurs only under certain well-defined conditions. As yet, fixation has never been found to take place in 'resting' material: active growth is essential. A further limitation is that assimilation of free nitrogen does not occur in the presence of readily available combined nitrogen. Thus ammonium salts or nitrates have an inhibiting effect, and fixation does not start until these compounds have been exhausted from the medium in which the algae are growing [8]. Although in pure culture growth on nitrate or ammonium nitrogen is as good as or better than that on free nitrogen, growth of nitrogen-fixing organisms in mixed culture tends to be suppressed by these compounds, since they are then exposed to the competition of organisms which do not fix nitrogen. Traces of molybdenum are necessary for the fixation of nitrogen by blue-green algae [6]. A slightly alkaline medium is the most favourable for the growth of nitrogen-fixing algae, and it has been found that fixation does not take place below approximately *p*H 5·7 [11].

Although it has so far been found impossible to extract the enzymes from the cells, there exists a good deal of information, obtained largely by physico-chemical methods, about the characteristics of the enzyme system responsible for nitrogen fixation in leguminous plants and in *Azotobacter* [1, 15]. The characteristics of the enzyme system in *Nostoc muscorum* have been investigated [16] and appear to be very similar to those found for other organisms. The half-maximum rate of fixation occurs at a partial pressure of nitrogen of 0·02 atmosphere. While this value is only provisional, it is evidently of the same order as that for *Azotobacter* (0·02 atmosphere) and for *Trifolium pratense* (0·05 atmosphere). Like those of *Azotobacter* and the symbiotic system, the enzyme system of *Nostoc* is specifically inhibited by hydrogen and by carbon monoxide. The biochemical mechanism by which fixation of free nitrogen is accomplished is still largely unknown, and so far studies on blue-green algae have contributed little towards the solution of the problems involved.

It is evident that the nitrogen-fixing system in blue-green algae is physiologically similar to that in other organisms. However, differences in general physiology render the natural role of these algae as nitrogen-fixing agents somewhat different from the parts played by *Azotobacter* or leguminous plants. An important respect in which blue-green algae differ from the nitrogen-fixing bacteria is that the former are photosynthetic whereas the latter are heterotrophic, dependent on already elaborated carbon compounds. Nitrogen-fixing blue-green algae are the most completely autotrophic organisms known, being able to synthesize their most complex biochemical requirements from carbon dioxide, water, free nitrogen, and mineral salts. Consequently these algae are able to flourish in situations where nitrogen-fixing bacteria cannot grow because of lack of carbohydrates, for example on bare rock faces and in open water. On the other hand, environments into which light cannot penetrate, such as all but the most superficial layers of soil, although suitable for bacteria, would appear unsuitable for algae. This is not, however, necessarily so, since some blue-green algae at least are able to grow and to fix nitrogen in the dark, provided that a suitable carbohydrate is available [10, 11, 17].

In combining the nitrogen-fixing and photosynthetic modes of nutrition, blue-green algae resemble the legume-nodule-bacteria system. However, in the latter the seats of photosynthesis and nitrogen fixation are spatially separated, carbon assimilation occurring in the green aerial parts of the plant and nitrogen assimilation in the root nodules. Even so, the two processes are closely interrelated [1]. In blue-green algae, in which nitrogen and carbon assimilation proceed side by side in the same cell, this association may

be yet more close. There may be, for instance, common intermediate compounds. In rate of growth blue-green algae are intermediate between bacteria and leguminous plants. Under favourable conditions of culture *Anabaena cylindrica*, for example, is able to double its bulk in a little under twenty-four hours [18].

The nitrogen fixed by blue-green algae eventually passes into general circulation and is assimilated by organisms unable to fix it for themselves. There are two possible ways in which the nitrogen compounds formed may be released. They may be excreted or lost by diffusion into the surrounding medium during the life of the algae, or they may be released by death and subsequent decomposition or digestion. The filtrate from healthy cultures of blue-green algae may contain a considerable proportion—up to 50 per cent.—of the nitrogen fixed in a soluble organic form [7, 8, 17]. Such excretion is relatively greatest in young cultures [19] and thus cannot be the result of autolysis of senescent cells. Since organisms unable to fix nitrogen are able to grow to a certain extent in healthy cultures of nitrogen-fixing algae, it seems that they are able to assimilate the excreted nitrogen compounds to at least a limited degree. Like other nitrogen-fixing organisms, blue-green algae have a high nitrogen content of from 7 to 8 per cent. on a dry-weight basis [18], and a correspondingly low carbon/nitrogen ratio of 10 : 1 [7]. The bacterial decomposition of organic matter with a carbon/nitrogen ratio of this low order will lead to the immediate production of ammonia [7], a form of combined nitrogen readily available for the growth of higher plants.

It remains to consider the importance of blue-green algae as nitrogen-fixing agents in the various habitats in which they are found. In any particular instance it is necessary to know, not only to what extent nitrogen-fixing species are present, but whether the physiological conditions are such as to allow the process to take place. The presence of available combined nitrogen and the absence of molybdenum would seem to be of chief importance in preventing the assimilation of free nitrogen. It has been shown [20] that traces of molybdenum are widely distributed in nature, and it seems safe to assume that sufficient for the fixation process is present in most habitats.

Blue-green algae are common in neutral or alkaline soils but are rarely present under acid conditions [21]. They are more abundant in the surface layers of soil [21], although the demonstration that some species at least are capable of heterotrophic growth suggests that they are not necessarily confined to the most superficial layers exposed to the light. Besides forms which have definitely been shown to be nitrogen-fixing, there are many other species which probably also possess the property. The concentration of nitrate in the soils in which they occur is generally sufficient to inhibit assimilation of free nitrogen, but it is probable that conditions of shortage of nitrogen compounds may arise locally—particularly on the surface—and permit the process to take place. While blue-green algae are of general occurrence in soils of agricultural value in temperate regions in which conditions suitable for nitrogen fixation may sometimes arise, it may be doubted whether their nitrogen-fixing powers are of much importance in contributing to fertility, since it has never been demonstrated that they occur in sufficient quantity.

In certain tropical soils, on the other hand, blue-green algae appear to be of extreme importance in maintaining fertility. In India, rice may be grown on the same land for many years without the addition of manure to the soil. During the season of growth of the rice the soil is waterlogged, and growth of blue-green algae, including several species that have been shown to fix nitrogen, is very luxuriant [7, 12]. There is good evidence that such algae are the main agents responsible for maintaining the level of fertility of the ricefields, and the part played by bacteria is probably unimportant [7].

Blue-green algae are frequently abundant in fresh water, the phenomenon of 'water bloom' being due to a copious growth of planktonic forms. They are especially characteristic of neutral or alkaline waters with relatively high contents of dissolved organic matter [22]. Some of the species concerned are *Anabaena*s and almost certainly fix nitrogen as has been claimed [23, 24], but rigid proof of this is still wanting. Other types of planktonic blue-green algae, for example *Gloeotrichia natans*, are still unexamined for nitrogen-fixing properties. At times when these organisms are most abundant the nitrate content of lake water is very low [22] and is probably not high enough to interfere with fixation. It has been reported [23, 25] that, in bodies of fresh water where they are abundant, these algae are the chief agents responsible for increases in the amount of combined nitrogen in the water. This is probably generally true, since the combined nitrogen of a 'bloom' of blue-green algae may be many times the amount of combined

nitrogen apparently available for its growth, and fixation of free nitrogen is therefore indicated [19]. *Myxophyceae* may thus contribute to a considerable extent to the productivity of fresh water in which they occur.

Blue-green algae are commonly the first plants to colonize bared areas of rock and soil. The best-known example of this is seen in the recolonization of Krakatoa after the volcanic explosion of 1883 which denuded the island of all visible plant life. Blue-green algae were the first plants to appear on the pumice and volcanic ash, on which they formed a dark-green gelatinous layer a few years after the eruption [26]. Members of the group are equally important pioneers under less impressive circumstances. Thus, to give only two of many possible examples, a community of blue-green algae forms the initial stage in plant succession on certain eroded soils [27], and *Myxophyceae* play a conspicuous part in the colonization and stabilization of salt marshes. In part, their success as colonizers is no doubt due to a marked ability to withstand adverse conditions such as desiccation, extreme temperatures, and high salt concentrations, but a capacity for nitrogen fixation cannot be discounted as a possible factor determining their presence on unpromising substrates. Again, there is no conclusive proof that among the blue-green algae which are conspicuous as colonizers some are able to assimilate free nitrogen, though many species occurring in lists of algae in pioneer plant communities belong to the *Nostocaceae* [26, 27]. There is, however, a certain amount of evidence that blue-green algae colonizing rocks under desert conditions are able to fix nitrogen and are therefore responsible for an accumulation of nitrate [14].

Besides free-living forms there are many blue-green algae that occur in more or less intimate association with other plants, for example with certain liverworts, with the water fern *Azolla*, with cycads, and with the flowering plant *Gunnera*. Many claims have been made that *Nostoc punctiforme*, the alga found in *Gunnera* and some cycads, is able to fix nitrogen, and in at least one case [10] the evidence appears sound. The species of *Anabaena* which are also found in such associations have not definitely been proved to possess the property. While in many cases these blue-green algae can be grown in artificial culture, this is sometimes difficult [6]. *Nostoc punctiforme*, isolated from cycads, has been found to be scarcely capable of autotrophic nutrition, and needs to be supplied with carbohydrate for growth and nitrogen fixation [10]. The host plant is generally able to exist if uninfected with the alga, and it is not clear how much benefit is derived from the nitrogen fixed. In some cases, for example that of *Azolla*, growth in a medium free from combined nitrogen is made possible by the presence of the algal partner [6]. There is thus a certain amount of evidence that these associations are symbioses, though they are neither so highly developed nor so successful as those between *Leguminosae* and their nodule bacteria. The plants concerned are not widely distributed, and if nitrogen fixation does occur it is not likely to be of very great importance either ecologically or economically. Blue-green algae form symbiotic associations with fungi as well as with green plants, the algal partner in many lichens often being a member of the *Myxophyceae*. Nitrogen fixation may well be important in enabling some of these composite organisms to live on bare rock and in other similarly inhospitable situations.

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Book reviews

HEAT-TREATMENT OF METALS

Controlled Atmospheres for the Heat-Treatment of Metals, *by Ivor Jenkins, with a foreword by C. J. Smithells. Pp. x + 532, with 268 figures, including many plates. Chapman and Hall Limited, London.* 1946. 50*s. net.*

The heat-treatment of metals in controlled atmospheres is a process of great and increasing practical importance. If carried out in the ordinary atmosphere, the various heat-treatments to which metals and alloys are subjected during manufacture generally result in surface oxidation. The loss of metal due to this and to the cleaning processes involved may be enormous. It is estimated, for instance, that the value of iron lost in this way amounted to about one million pounds sterling per annum in Britain alone prior to 1939, and in non-ferrous metals the losses are probably similarly expensive. To reduce these losses and ensure a proper finish, suitable atmospheres must be employed, but this is not such a simple matter as merely protecting the metal from oxidation. With steels, carburization and decarburization of the surface layers must be controlled, and nitride-hardening may be desirable; with copper, embrittlement due to deoxidation must be avoided. The essence of the problem is generally to ensure a state of true equilibrium between the atmosphere and the metal over the range of temperature employed.

Despite the extremely technical nature of the subject, this is a remarkably readable book. The problems belong essentially to physical chemistry rather than to metallurgy, and the book begins with a simple and very clear treatment of chemical equilibria and some discussion of gas-metal systems. The generation of commercially feasible controlled atmospheres (derived from ammonia, hydrocarbons, or charcoal) is then described. An excellent section on analysis is followed by a very full account of industrial applications of controlled atmospheres to various steels and alloys. The fundamental scientific problems involved are stressed throughout the book, and the result is a work of really great interest to the student and academic worker as well as to practitioners in this important field. The publishers are to be congratulated on their production of an attractive volume of unusually high quality.

J. M. ROBERTSON

CRYSTALS AND MINERALS

Kristalle und Gesteine, ein Lehrbuch der Kristallkunde und allgemeinen Mineralogie, *by P. Eskola. Pp. viii + 397, with 461 figures. Springer-Verlag, Vienna.* 1946.

This work, which first appeared in Finnish and is now available in a revised German translation, is divided into five sections of approximately equal length—crystal geometry, crystal physics, crystal chemistry, petrology, and systematic mineralogy.

Within this compass it is clear that the treatment of the subjects indicated cannot be deep; nevertheless the material of the general survey is presented in an attractive form. The author finds room to include tables of the 230 space-groups, short notices on Fourier analysis, radioactivity, geochemistry, and petrofabric analysis, but here the presentation is all too brief.

In the section on metamorphism of rocks the treatment follows closely, though in an abbreviated form, that presented by the author in *Die Entstehung der Gesteine* (1939).

The last section gives a brief survey of crystal types, with special attention to substances illustrating the variety of crystal structures met with among minerals.

The volume is well printed and illustrated and provides an outline of the broad field of study among crystals and rocks.

C. E. TILLEY

SILK

Bibliography of the Technical Literature on Silk, *by F. O. Howitt. Pp. xxiv + 248. Hutchinson's Scientific and Technical Publications, London.* 1946. 21*s. net.*

Students, research workers, and technologists whose work and studies touch upon the production, properties, and processing of silk at any stage will find in Dr Howitt's critical and exhaustive review of the published literature on silk an indispensable aid and will be grateful to the Council of the British Cotton Industry Research Association for sponsoring its publication.

Such is the antiquity and wide geographical distribution of silk that it has acquired to itself almost a technical word-group of its own, and readers will find the Glossary of Silk Terms, with which this bibliography opens, of considerable service.

The fifteen chapters of the bibliography itself review successively the literature of silk cultivation as it affects subsequent processing, the properties of raw silk, silk gum, and degummed silk, the preparation of nett silk yarns, the bleaching, degumming, weighting, and dyeing of silk, silk weaving and knitting, the preparation of spun silk yarn, the finishing of silk goods, the testing of silk, and uses of silk other than in textiles.

The references are conveniently grouped by chapters and are supplemented by patent, subject, and author indexes for the whole volume.

The author's specialist knowledge and experience enable the critical level of the survey to be maintained throughout, attention being directed frequently to problems of fundamental scientific and technical value on which published information is either inadequate or altogether lacking.

E. B. ABBOT

ENGLISH PATENT LAW

Inventions, Patents, and Monopolies, *by P. Meinhardt. Pp. 352. Stevens and Sons Limited, London.* 1946. 25*s. net.*

One rarely finds a book of law which can be read and enjoyed like a good novel. Mr Peter Meinhardt, however, can make this claim for his book on Inventions, Patents, and Monopoly. A book interesting to the legal expert and lay reader alike, it should make a particular appeal to the scientist who would like to know something of the spirit behind English patent law and its *modus operandi*. He examines the relationship between inventors and the general public and traces the development of English patent law, dealing clearly and in detail with its current practical administration.

A description of the various abuses of patent monopoly rights follows. At a time when economic reform is the order of the day and widely publicized allegations of patent abuses, often sweeping and largely inaccurate, are levelled at industrialists, the book makes a useful contribution to a clarification of the issues.

The author concludes with some suggestions for patent law reform, including an interesting one to divide patents into 'licence patents' and 'full patents,' the classification to depend upon the degree of ingenuity displayed in the invention. The monopolistic protection accorded would be likewise graded. The weight which the precedents of case law should carry in patent actions is also discussed.

L. R. BATTEN

VOL. XV

Notes on contributors

KATHLEEN LONSDALE,
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Was born in 1903 and was educated at Bedford College, University of London. From 1922 to 1927 she investigated the structure of simple organic and inorganic crystals by X-ray methods as a member of Sir William Bragg's research team, first at University College, London, and later at the Royal Institution. In 1927, upon her marriage, she moved to the University of Leeds and there continued her X-ray crystallographic research and collaborated in the production of the 'International Tables for Crystal Structure Determination.' In 1932 she returned to the Royal Institution, publishing 'Structure Factor Tables' in 1936, and continuing research upon the structure and properties of crystals, first as Leverhulme Fellow and later (1945) as Dewar Fellow. In 1945 she was elected a Fellow of the Royal Society, being one of the first two women ever to be elected. She has now taken up a new position as Reader in Crystallography in the Chemistry Department of University College, London.

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Was born in 1877 and was educated in Guernsey and at the University College of Wales, Aberystwyth. From 1901 to 1904 he was Fellow of the University of Wales, spending eighteen months as Research Student at the University of Zürich. In 1917, after previously holding a lectureship in natural history, he was appointed Professor of Geography and Anthropology, University College of Wales. From 1930 to 1944 he was Professor of Geography in Manchester University. In 1940 he was president of the Manchester Literary and Philosophical Society, about which he writes in this issue.

T. A. STEPHENSON,
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Was born in 1898. After eight years as Lecturer in Zoology at University College, London, he was in 1931 appointed Professor of Zoology in the University of Capetown. In 1941 he took up his present post of Professor of Zoology in University College, Aberystwyth. He was in charge of the section of the Great Barrier Reef Expedition (1928–9) which studied shore ecology. This section worked on corals and the various invertebrates and seaweeds associated with them. During his tenancy of the chair at Capetown he carried out, with the help of a dozen assistants, a biological survey of nearly two thousand miles of the South African coast between tidemarks; this was the most extensive piece of work of its type to be undertaken. He has published various papers on sea anemones, culminating in a two-volume monograph on the British species, published by the Ray Society in 1928 and 1935; a series of papers on coral biology in the Scientific Reports of the Barrier Reef Expedition, 1931–4; and another series, still continuing, on the results of the South African survey. His book *Seashore Life and Pattern* was published in 1944. He is keenly interested in painting as well as in biology.

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Has been Sherardian Professor of Botany in the University of Oxford since 1937. Was born in 1887 and was educated at Burnley Grammar School and the University of Manchester. From 1908 to 1912 he was Lecturer in Economic Botany at the University of Manchester. In 1912 he became Professor of Botany at the University of Adelaide and Consulting Botanist to the South Australian Government. From 1928 to 1937 he was Professor of Botany in the University of Sydney. He has studied ecological problems relating to grasslands in both Australia and Britain and has been a member of the Agricultural Research Council since 1943.

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Was born in 1901 and was educated at the University of Manchester, specializing in zoology. After studying entomology at Imperial College, London, he became Government Entomologist in Nigeria in 1925. Since 1930 he has made a special study of the breeding and control of locusts. In 1932 he joined Imperial Chemical Industries Limited and continued his entomological researches. In 1942 he was seconded to the British Government for locust control work in the Middle East, where he served in Iran before becoming Chief Locust Officer in Cairo. He has since studied locust control in most of the affected countries of the Middle East, Africa, and South America and was responsible for defining the outbreak area of the African Migratory Locust in the French Sudan.

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Was born in 1919 and was educated at Dulwich College, Queen Mary College, London, and St. John's College, Cambridge. After graduating he undertook research, under Professor F. E. Fritsche, on nitrogen fixation by blue-green algae. During the war he took part in a survey of the seaweed resources of the British Isles and carried out research on the control of weeds by chemical methods. He is now Lecturer in Plant Physiology at University College, London.

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